Learning from engagement: exploring cultures of science communication at live science events

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Published work and a critical commentary submitted in partial fulfilment of the requirements of the University of the West of England, Bristol, for the degree of Doctor of Philosophy by publication (DPhil) 2018.

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Abstract

This thesis is submitted to meet the requirements of a Doctorate of Philosophy within the field of Psychology. Through a series of nine publications, this body of work aimed to develop a deeper psychological understanding of cultures of science communication at live science events in order to better support audiences and practitioners. Live science events encompass an enormous diversity of activity ranging from science festivals to education outreach in schools. While the scale and audiences may vary, they are all live, in-person programmes aiming to engage the public with science in a social context. Science communication practitioners (including scientists and engineers) and audiences report that live science events provide powerful experiences to engage with science, but empirical measurements of these impacts are sparse.

As such, these publications and the associated commentary have sought to advance future research and practice in science communication on this topic. The DPhil had three objectives: to analyse audience perceptions of and needs for engagement formats and learning at live science events; to explore science communication cultures in STEM research environments and live science events; and to evaluate and influence the motivations and perceived self-efficacy of STEM researchers/students taking part in engagement and outreach. Through leading these projects and publishing the results, the candidate has met the requirements of the UWE Doctoral Descriptors. The insights from these projects have proven applicable to both researchers and practitioners in the science communication and science education industries, and will help to drive forward best practice in the field.

1. Bibliography of Publications

Table 1: Role within each publication submitted for this DPhil

Publication and Appendix	Role	UWE Doctoral Descriptor
A) **Fogg-Rogers, L.,** Bay, J.L., Burgess, H., and Purdy, S.C. (2015). 'Knowledge is power': a mixed methods study exploring adult audience preferences for engagement and learning formats over three years of a health science festival. *Science Communication,* 37 (4). pp. 419-451. ISSN 1075-5470 Available from: http://eprints.uwe.ac.uk/25328	• Contributed to the overall concept and design of the project • Completed the literature search • Managed and conducted qualitative and quantitative data collection • Conducted quantitative and qualitative data analysis for the whole project • Wrote the final paper • Disseminated the findings	1 2 3 4 5 6
B) Bay, J.L., Tan, R., Spiroski, A., **Fogg-Rogers, L.,** McCann, C. Barber, A. and Faull, R.L.M. (2015). Stroke Awareness and Knowledge in an Urban New Zealand Population. *Journal of Stroke and Cerebrovascular Diseases*, 24 (6). pp. 1153-1162. ISSN 1052-3057 Available from: http://eprints.uwe.ac.uk/24599	• Contributed to the overall concept and design of the project • Contributed to editing the final paper • Disseminated the findings	1 3 4 5
C) France, B., Bray, B. and **Fogg-Rogers, L.** (2015). Organisational culture and its role in establishing a sustainable science communication platform. *International Journal of Science Education, Part B: Communication and Public*	• Contributed to the overall concept and design of the project • Conducted a literature review • Contributed to the writing of the paper	1 2 3 4 5

Engagement, 7 (2). pp. 146-160. ISSN 2154-8455 Available from: http://eprints.uwe.ac.uk/27481	• Contributed to the dissemination of the findings	6
D) Durant, J., Buckley, N., Comerford, D., **Fogg-Rogers, L.,** Fooshee, J., Lewenstein, B. and Wiehe, B. (2016) Science Live: surveying the landscape of public science events. Project Report. MIT, Cambridge, USA. Available from: http://eprints.uwe.ac.uk/29112	• Contributed to the overall concept and design of the project • Completed the literature search • Conducted qualitative data collection and analysis for the whole project • Produced the project results • Contributed to the dissemination of the findings	1 2 3 4 5 6
E) **Fogg-Rogers, L**., Grand, A. and Sardo, M. (2015) Beyond dissemination - science communication as impact. *Journal of Science Communication*, 14 (3). C01-CO7. ISSN 1079-6533 Available from: http://eprints.uwe.ac.uk/27106	• Contributed to the concept of the commentary • Wrote the final commentary	1 2 5
F) **Fogg Rogers, L.,** Sardo, M. and Boushel, C. (2017) Robots vs animals: Establishing a culture of public engagement and female role modelling in engineering higher education. *Science Communication*, 39 (2). pp. 195-220. ISSN 1075-5470 Available from: http://eprints.uwe.ac.uk/30921	• Solely responsible for designing and funding the project • Project managed the entire research programme • Conducted the literature search • Analysed the quantitative and qualitative data • Wrote the final paper • Disseminated the findings	1 2 3 4 5 6

G) **Fogg-Rogers, L.** (2017) Does being human influence science and technology? *Journal of Science Communication*, 16 (4). Available from: http://eprints.uwe.ac.uk/32954	• Conceptualised and wrote the commentary	1 2 5
H) **Fogg-Rogers, L.,** Edmonds, J. and Lewis, F. (2017). Paired peer learning through engineering education outreach. *European Journal of Engineering Education*, 42 (1). pp. 75-90. ISSN 0304-3797 Available from: http://eprints.uwe.ac.uk/29111	• Contributed to the design and funding of the project • Project managed the entire research programme • Conducted the literature search • Conducted the quantitative and qualitative data collection with engineers • Analysed the quantitative and qualitative data for the engineers • Wrote the final paper • Contributed to the dissemination of the findings	1 2 3 4 5 6
I) **Fogg-Rogers, L.** and Moss, T. (2018) Validating a scale to understand engineers' perceived self-efficacy for engineering education outreach. Submitted to *Learning and Individual Differences*.	• Solely designed a new scale for measuring engineering education outreach self-efficacy • Contributed to the validation design for the scale • Conducted the quantitative data collection and statistical analysis • Wrote the final paper	1 2 3 4 5 6

2. Introduction

The body of work presented in this doctoral thesis brings together several years of research and practice in live science events. I came to work in the Science Communication Unit (SCU) at the University of the West of England, Bristol (UWE) in 2013, bringing lived experience as a practitioner in television, communications, and event production. I had undertaken a Masters level research thesis in Psychology, and was interested in developing my understanding of the underpinning theory behind how and why certain events 'worked'. The SCU's description of itself resonated with my experience:

> *"The Science Communication Unit is recognised for its leadership in defining, targeting and engaging audiences with science. This expertise is:*
> - *Creative and insightful*
> - *Built on a sound evidence base*
> - *Grounded in theory and practice*
> - *Developed in partnership with others*
> - *Used by others to build capacity in engaging audiences with science".*

> (Science Communication Unit 2018)

However, I felt that literature in the science communication field did not fully explain the cultures of live science events for audiences or practitioners, or underpin the outcomes and impacts of these experiences. That is why this Doctorate of Philosophy (DPhil) sits within the field of Psychology, as it allows the scientific study of the human mind and behaviour. In particular, I have drawn on the field of Social Psychology and specifically Social Cognitive Theory, as well as literature from Informal Science Learning.

Integrating these fields and ways of working has much to benefit science communication. Practically, academics from all these fields work on the same contexts, participants, and research questions. However, each field approaches the research topics with different theories, methodologies, and prior literature. Through a series of studies assimilating this diverse range of literature and theories, and through exploring different aspects of live science events, this DPhil provides novel insights into cultures of science communication experienced by both audiences and practitioners at these events. It will also explore the organisational cultures that enable these events to take place, and how to support the perceived self-efficacy of scientists and engineers to take part. Through its nature of being a DPhil, this programme of work does not aim to definitively address these questions, but instead contributes to the progression of knowledge in a stepwise fashion.

2.1 Aim and objectives

This commentary will outline my area of research, and then critically reflect on each publication and its contribution to original knowledge. I will outline my methodological development and epistemological position, and finally synthesise this learning for the advancement of future research and practice in science communication.

Overall, this DPhil aims to develop a deeper psychological understanding of cultures of science communication at live science events in order to better support audiences and practitioners. In particular, the objectives are:

i. To analyse audience perceptions of and needs for engagement formats and learning at live science events

ii. To explore science communication cultures in STEM research environments and live science events

iii. To evaluate and influence the motivations and perceived self-efficacy of STEM researchers/students taking part in engagement and outreach

2.2 Declaration of Authorship and Training

I confirm that all of the work presented in this doctoral thesis, including the selected publications and accompanying Commentary (except where stated), is the original work of the author.

I confirm that none of the published body of work included within this portfolio of selected publications has been submitted for another academic award either in this or any other institution.

I confirm that the necessary training requirements have been met:

- Conducting and Evaluating Psychological Research (USPK7Y-30-M) (30 credits)
- Accredited Learning: Research in Contemporary Contexts (USSJLK-30-M) (30 credits)

Ms Laura Alice Fogg-Rogers, 2018

3. Background

International funding and policy requirements are currently driving scientists and engineers to deliver public engagement and impact from research (Palmer & Schibeci, 2012; Research Councils UK, 2010). There are many different science communication practices in the UK, which all form part of the wider public engagement landscape (Durant et al. 2016). While recognising the differences between 'public engagement' as a two-way process and 'communication/dissemination' as a one-way process (Rowe & Frewer 2005; Irwin 2008), in practice, it is difficult to distinguish among the many interactions that occur over time between scientists, engineers and wider publics. Indeed, previous research has indicated that UK science communication practitioners interchangeably use the terms 'education outreach', 'science communication', 'informal science learning', and 'public engagement' (Illingworth, Redfern, Millington, & Gray, 2015); perhaps due to the disconnect between the correct meaning of these terms and their use in practice. However, this DPhil does not seek to define or categorise communication mechanisms; instead it intends to explore all forms of science communication activities which take place at live science events.

3.1 Live Science Events

Live science events encompass an enormous diversity of activity ranging from science festivals to education outreach in schools. While the scale and audiences may vary, they are "all live, in-person programmes designed to engage the public with science in a social context that is at least as meaningful as the content and messages delivered" (Durant et al., 2016, i). Even in an increasingly digital world, events are well attended by audiences, with over 10,000 live events with an explicit science focus produced for the public in the USA and UK every year (Durant et al. 2016).

Science communication practitioners (including scientists and engineers) and audiences report that live science events provide powerful experiences to engage with science, but empirical measurements of these impacts are sparse (Weihe 2014). The informal environment of live science events tends to attract multi-generational audiences, necessitating a mix of communication aims and methods (Grant 2004; Durant 2013). Theoretically, this informal environment should enable a variety of science communication, learning, and engagement practices to coincide (Holliman et al. 2009), along with multiple impacts from such events for both practitioners and audiences; however this has not been a focussed area of research.

Much debate exists about styles of communication at live public science events, and which is most beneficial for audiences. Live science events have been criticised for relying on traditional one-way science communication techniques such as lectures (Riise 2008), and urged to include more dialogic-style formats (House of Lords Select Committee on Science and Technology, 2000). This 'grand narrative' of science communication (Trench 2008), indicates that top-down, packaged communication of scientific information does not work (Wynne 2006). Instead, the 'buzzword' of 'public engagement with science' (Bensaude Vincent 2014) has become commonplace to indicate publicly-engaged science aiming to open up science and its governance (Stilgoe et al. 2014). Public engagement is defined as "a two-way process, involving interaction and listening, with the goal of generating mutual benefit" (National Coordinating Centre for Public Engagement 2014). It is notable that scientists applying to take part in science festivals in the UK are now mainly encouraged to develop hands-on activities enabling two-way dialogue and interaction with the public (University of the West of England 2014; Bristol Food Connections 2014; Festival of Nature 2014; Wellcome Trust 2014).

It has been argued that this two-way singular interaction view of public engagement does not reflect: 1) the aims of many scientists taking part in engagement activities, that is to inspire, raise awareness, and improve public knowledge (Besley et al. 2013), or 2) the drive to evaluate effectiveness of engagement activities for learning (Trench 2008). One of the aims of this DPhil is to explore whether these objectives also fit with audience needs and expectations.

3.2 Organisational cultures of public engagement

Despite funding and policy reports urging scientists to participate in public engagement, numerous surveys have indicated that scientists and engineers view these activities as voluntary work which is additional to their main academic responsibilities (Andrews et al. 2005; Besley & Nisbet 2011; Bauer & Jensen 2011). The majority (61%) of 1558 UK Science, Technology, Engineering and Mathematics (STEM) researchers surveyed in 2015 indicated that public engagement activities are seen as detracting from competing demands on their time for research and career progression (TNS 2015). The activities surveyed included giving a public lecture, participating in public dialogue/debates, working with schools, working with museums, and engaging in cultural performances or the entertainment industry. The majority of researchers surveyed (71%) had not received any training for these activities (TNS 2015).

Several studies have explored which factors predict participation in science communication and public engagement activities. Discipline is critical, with physicists more likely to view participation as a threat to personal reputation, while biologists are more likely to view it as part of their role (Johnson et al. 2014; Ecklund et al. 2012). Gender is also influential with men more likely to take part in media interviews (Crettaz von Roten 2011), while women are more likely to take part in activities with children (Johnson et al. 2014). Career stage is also a factor (TNS 2015), with Bauer and Jensen (2011) indicating that senior academics undertake most public engagement. Surveys of scientists active in public engagement have indicated that a personal commitment to the public good, professional obligation, and feelings of enjoyment and personal efficacy are strong predictors for participation (Besley et al. 2013; Martin-Sempere et al. 2008).

Beyond these personal identifiers, decisions at an organisational level have also been found to be influential; indeed, approved workload time was the most cited factor (at 48%) that would increase public engagement activity by scientists surveyed in the UK (TNS 2015). Similarly, professional communication training (Trench & Miller 2012) and administrative support from science communication coordinators (France et al. 2015) have been cited as beneficial for researchers. Furthermore, visible supportive leadership and descriptive norms (whether scientists believe their colleagues participate) (Poliakoff & Webb 2007; Dudo 2013; Marcinkowski et al. 2014) have all been implicated in generating an organisational culture of science communication, that is, an environment where public engagement activities are considered a normal and beneficial thing for STEM researchers to do. Indeed, it has been asserted that significant culture change will not happen without scientists receiving recognition for their efforts and a supportive infra-structure being provided in which such engagement can take place (Poliakoff & Webb 2007).

3.3 Engineering education outreach

One such field trying to stimulate organisational culture change is engineering, where policy and economic drivers are encouraging engineers to reach out to more diverse sectors of society in order to improve participation (Perkins 2013; EngineeringUK 2017). Education outreach is one form of public engagement whereby non-teaching professionals engage with young people in informal or formal learning environments (Jeffers et al. 2004; Fogg-Rogers, Lewis & Edmonds 2017). Whilst education outreach does not fit with the model of two-way communication outlined by the public engagement community (National Coordinating Centre

for Public Engagement 2014), it is in fact one of the most common ways that scientists and engineers undertake public engagement (TNS 2015). Indeed, it has been identified as a critical route to influence public perceptions and capabilities for STEM careers, and in particular for the future engineering workforce (Perkins 2013; EngineeringUK 2017).

By engaging with schools and communities, it has been shown that engineers can increase children's interest and engagement with STEM subjects (Callahan & Nadelson 2011) and also change their views of scientists and engineers (Wilkinson & Sardo 2013), while teachers also value expert contributions to STEM knowledge (Laursen et al. 2007). Attitudes at primary school in particular can influence later interest in STEM, especially for girls who develop their gender identity and consequently the appropriateness of STEM as a career before entering secondary school, typically by the age of 11 in the UK (EngineeringUK 2017; Archer et al. 2012; Murphy & Whitelegg 2006). Several education outreach programmes have shown specific improvements in children's attitudes towards engineering (Callahan & Nadelson 2011; Stapleton et al. 2009; Molina-Gaudo et al. 2010), along with stable (not declining) recruitment to local engineering higher education programmes (Davis et al. 2012; Martínez-Jiménez et al. 2010).

As more engineers undertake education outreach, it is becoming more important to assess the impact of these activities on the engineers themselves. Public engagement has been found to benefit engineers, enabling the development of generic skills such as communication and teamwork required in professional environments (Pickering et al. 2004; Direito et al. 2012). Incorporating public engagement within undergraduate engineering programmes provides a key learning opportunity for students to gain opportunities to practise their public engagement and education outreach skills, before entry to the workplace (Fogg-Rogers, Edmonds, et al. 2015). Working with the community also provides service learning (Duffy et al. 2008; Oakes et al. 2002), which enhances the employability of student engineers through working towards professional codes such as the UK Standard for Professional Engineering Competence (UK-SPEC) and professional status awards such as Engineering Chartership (Owen & Hill 2011).

3.4 Self-efficacy for outreach and engagement

Participation in public engagement activities is therefore affected by both individual capabilities and beliefs and also by the normative beliefs and support networks in an organisation. Social cognitive theory provides much insight into the mechanisms behind these factors, indicating that an individual's learning is not only related to their personal capabilities and experience, but also to their observations of others within the context of social interactions, experiences, and outside media influences (Bandura 2004; Bandura 2001). In other words, an individual will not perform a behaviour just because they have mastered it; they may or may not replicate this behaviour depending on the outcome of the behaviour and how others react to it socially (Bandura 1977; Bandura 1976; Bandura 2001).

As the author of this theory, Bandura (1977) developed a way to measure these varied influences on an individual through their perceived self-efficacy (PSE). PSE is a measure of belief in personal capabilities to produce specific actions, reflecting perceptions of capability rather than measuring actual performance; however, people with high PSE are more likely to continue performing that action (Bandura 2004). PSE is specific to each domain of activity (Bandura 2006), so while STEM researchers may have high PSE for communicating their subject knowledge with fellow academics, they may have low PSE for undertaking public engagement activities with wider publics. This is important, as despite many funding and policy drivers urging more public engagement activity, the literature reviewed above indicates that scientists and engineers need to feel that these activities and behaviours are worth performing in order to do it; social and cultural influences are critical in this respect.

Research into self-efficacy indicates that while PSE is innately determined by natural capabilities to some extent (Declerck et al. 2006), it can be influenced and improved. A critical way to improve PSE is through successful direct learning experiences. This mastery over a task encompasses experiencing personal performance with an accompanying positive emotional arousal (Bandura 1998); this may be why training and supportive starter programs in public engagement are helpful (Trench & Miller 2012). Alongside this, experiencing social persuasion through peer approval or coercion validates that the behaviour is normative and worthwhile (Bandura 1998; Anderson & Betz 2001); that is, researchers need to receive a reward or extrinsic recognition in some form from their peers or leaders in order to keep doing public engagement activities.

Indirect learning experiences are also useful to improve PSE; these are derived from vicarious modelling - watching others perform the activity successfully (Bandura 2004). This is

important for women in STEM, and is commonly known as role modelling. Indeed, research with so-called 'successful people' in STEM indicated that while mastery experience was the primary source of men's PSE beliefs, social persuasion and vicarious modelling were more important for the women in the study (Zeldin et al. 2008). This gender difference highlights that a range of experiences may be necessary to generate a sustainable organisational culture of public engagement in higher education, with the resulting influences on societal perceptions of STEM. In particular, girls need to see women performing STEM activities successfully in order to believe that STEM is for them, while female researchers need to see their fellow women academics succeeding in both their research careers and with public engagement activities in order to stay in STEM professions. Visibility of women therefore ensures the social acceptability of girls being recruited into STEM, and once there, that they are retained within this career path.

Evidence therefore suggests that providing engineers with training programmes and structured public engagement experiences can boost PSE to perform public engagement activities (Dudo 2013; Robertson Evia et al. 2017), ensuring better quality and more frequent public engagement. While much work exists to explore the impact of outreach on young people, there has only been one validated measure for assessing the outcomes for scientists themselves. The Self-efficacy for Public Engagement with Science scale measures scientists' self-efficacy for taking part in public engagement activities (Robertson Evia et al. 2017). A similar scale to measure engineers' PSE for education outreach activities has the potential to enhance research into science communication training, as well as improve engagement practice for enhanced experiences for young people. Thus this DPhil concludes with the validation of a scale to measure the construct of PSE for engineering education outreach, aiming to influence more effective science communication participation, research, and practise.

4. Critical Reflection on Publications

The publications listed here include one international project report and eight peer reviewed international journal papers. This section provides a critical reflection on the knowledge created by the papers, and addresses how the candidate therefore meets the UWE Doctoral Descriptors. The methods used in the papers and the UWE Doctoral Descriptors will be described in more detail in Section 5.

4.1 Ethics

All the research outlined in this commentary has received Ethics Approval from the relevant Ethics Committees. Research conducted in New Zealand was approved by the University of Auckland Human Participants Ethics Committee (Publications A, B, C). Research conducted in the USA was approved by the MIT Institutional Review Board (Publication D). Research conducted in the UK was approved by the UWE Faculty of Environment and Technology Research Ethics Committee (Publications D, F, G, I).

Many of my projects have involved working with children and vulnerable adults, and as such I hold a Disclosure and Barring Service check and I am knowledgeable about Safeguarding Children. I have organised several large events and I am experienced at managing Health and Safety for the public at these events. Ethical considerations for working with human participants were taken into account at all stages of the research process.

4.2 Evaluation of Brain Day Auckland - commentary on publication A

> **Fogg-Rogers, L.,** Bay, J.L., Burgess, H., and Purdy, S.C. (2015). 'Knowledge is power': a mixed methods study exploring adult audience preferences for engagement and learning formats over three years of a health science festival. *Science Communication,* 37 (4). pp. 419-451. ISSN 1075-5470 Available from: http://eprints.uwe.ac.uk/25328

This project was undertaken in New Zealand from 2011-2013, at the start of my interest in research into live science events. I was aware of literature discussing deficit and dialogue models of science communication (e.g. Rowe & Frewer, 2005) and I wanted to further explore how these dynamics played out in a practical environment. I was undertaking my MSc in Psychology at the time, and my supervisor Professor Suzanne Purdy offered to help me progress my research skills through co-designing this study.

In parallel to my MSc, I was also the Communications Manager for the Centre for Brain Research at the University of Auckland. I was responsible for organising a major science festival in Auckland, themed around neurological research and termed 'Brain Day'. The annual festival was a free day of lectures, discussions, experiments, and expos, and regularly attracted 3000 members of the public. I was responsible for organising all the events and interactions featuring scientists, as well as liaising with community groups and volunteer ambassadors. As such, it offered a good opportunity to plan research data collection into the event, and to run this consecutively over a three year period (2011-2013).

The questionnaire was designed by myself and Professor Purdy, and utilised quantitative and qualitative questions to provide a deeper understanding of audience needs and outcomes from the event. We aimed to find out more about what types of people were attending the event, why they were coming, which format they preferred, and what reasons they gave for this. The question styles drew on social science research methods (Denscombe 2010b), and included open format, demographic multiple choice, Likert rating scales, and Rank List questions. I learnt much from organising and planning the delivery of this questionnaire, and it was my first introduction to large-scale research management.

Data collection was organised by myself and Dr Jacquie Bay, and was supervised on the day by Hannah Burgess, a student volunteer. The data were then stored for three years until I found time to analyse it in depth. Data analysis began in earnest in 2014, when I was more skilled in descriptive and analytic statistics through the help of Dr Deidre Toher from UWE's Statistics Research Cluster. I analysed the large-scale dataset (N=661) for differences between demographics and over time. I also undertook a qualitative thematic analysis (Braun & Clarke 2006) to find inductive themes within the reasons for attendance and format preferences.

Contrary to the direction of the international literature which indicates that science communication practice should move away from traditional expert dissemination (Wynne 2006; Miller 2001), the lectures were significantly ranked the highest as the main attraction for attending the event, and this was irrespective of the year the festival was held, age group, or gender (Fogg-Rogers, Bay, Burgess, et al. 2015). They were also the most highly attended and most useful format as rated by audiences. The rankings for this format were highly statistically significant, and this boosted my confidence to conduct original research, which challenges established thinking. The thematic analysis revealed five themes that centred on non-formal learning, highlighting knowledge/understanding acquisition is perceived by audiences as empowering greater health literacy.

I presented this research in 2014 at a national conference:

> Fogg-Rogers, L. (2014) Knowledge is power: audience preferences for engagement and learning at a science festival. In: *Engage 2014,* Bristol UK, 3-4 December 2014. Available from: http://eprints.uwe.ac.uk/34404

I wrote the journal paper in 2015 and went through a lengthy peer-review process with the esteemed journal Science Communication; this was my first experience of journal submissions and it was certainly a learning curve. In order to contexualise this research, I had to draw widely on previous research in science communication, health communication, and health literacy fields. I completed and wrote much of the analysis and write-up for this paper, which was then edited with my collaborators.

The paper has been cited 10 times, has an Altmetric of 12 and has been downloaded from the UWE Repository 112 times. This project and publication provides evidence that I meet 1 to 6 inclusive of the UWE Doctoral Descriptors.

4.3 Māori stroke awareness - commentary on publication B

> Bay, J.L., Tan, R., Spiroski, A., **Fogg-Rogers, L.,** McCann, C. Barber, A. and Faull, R.L.M. (2015). Stroke Awareness and Knowledge in an Urban New Zealand Population. *Journal of Stroke and Cerebrovascular Diseases*, 24 (6). pp. 1153-1162. ISSN 1052-3057. Available from: http://eprints.uwe.ac.uk/24599

Through undertaking the work on Brain Day Auckland, it became apparent that the live science event was not serving the needs of Māori and Pacific Peoples. Only 1.9% and 1.7% respectively of the Brain Day audiences were from these ethnic backgrounds, which was a very low representation compared to population averages (11% Māori, 14% Pacific Peoples) (Statistics New Zealand 2013). This in fact reflects findings from international work, indicating that live science events do not attract many people from minority ethnic groups (Manning et al. 2013).

Through discussions with my collaborators on Publication A, we decided that we would need to find a topic which was of interest to these groups, and undertake events in places that they already attended. Stroke is the third most common cause of death and a major cause of chronic disability in New Zealand (Child et al. 2011). Māori and Pacific Peoples have a higher than average stroke risk compared to the New Zealand population (Carter et al. 2006), and as such, we felt that this neurological topic would be of interest to them. Initially, we wanted to design a live science event for this audience, which would communicate some of the latest research about how to reduce stroke risk. However, an initial literature search revealed that very little was known about how much Māori and Pacific Peoples already knew about stroke and the risk factors.

We therefore needed to firstly undertake a study to assess audience needs for public engagement around this topic. I co-designed the empirical study aimed at evaluating the awareness of these audiences towards stroke and its risk factors. I contributed to the design of the questionnaire, which was undertaken as short snapshot interviews outside shopping malls. Several areas across the urban Auckland area were sampled to reach a diversity of participants (N=850, with 11% Māori and 13% Pacific Peoples). Pacific Island respondents were significantly less likely than New Zealand Europeans to identify a number of stroke risk factors, and Māori, Pacific Island, and Asian respondents were significantly less likely to identify symptoms of stroke and indicate the need for urgent medical attention (Bay et al. 2015).

This indicated that further work would need to be undertaken to communicate research into this neurological condition, as well as indicating that current public engagement efforts at the Centre for Brain Research were not necessarily working for Māori and Pacific Peoples. This prompted further Public Patient Involvement work through the Centre's Māori Advisory Board (Centre for Brain Research 2014), enabling deeper collaboration and public engagement with these audiences.

I presented this research in 2014 at a national conference and also wrote it up into a collection of essays:

- Fogg-Rogers, L. A. and Mat Hickman, Wellcome Trust, Hema Teji, British Science Association (2014). The people, the people, the people: Engaging under-served audiences. In: *Science Communication Conference 2014*, Guildford, Surrey, UK, 1-2 May 2014. Available from: http://eprints.uwe.ac.uk/23007
- Fogg-Rogers, L. A. and Hickman, M. (2014). The people, the people, the people: Engaging under-served audiences. In: British Science Association (2014) *Collected Thoughts 2014: Essays Inspired by the Annual Science Communication Conference.* London: British Science Association, pp. 1-5. Available from: http://eprints.uwe.ac.uk/23497

I then co-edited the journal paper which was published in 2015. This publication indicates that I meet numbers 1, 3, 4 and 5 of the UWE Doctoral Descriptors. This paper has been cited by three others and has been downloaded 78 times from the UWE Repository.

4.4 Cultures of science communication - commentary on publication C

> France, B., Bray, B. and **Fogg-Rogers, L.** (2015). Organisational culture and its role in establishing a sustainable science communication platform. *International Journal of Science Education, Part B: Communication and Public Engagement*, 7 (2). pp. 146-160. ISSN 2154-8455. Available from: http://eprints.uwe.ac.uk/27481

In 2011, the breadth of public engagement activities at the Centre for Brain Research began to attract media interest focussing on our communications with people with neurological conditions. This in turn meant that science communication researchers began to be interested in how the Centre for Brain Research was organised and operated. I was contacted by Associate Professor Bev France and Dr Belinda Bray in order to collaborate on a science communication evaluation project. They were interested in the culture of science communication in the Centre, particularly focussing on how the scientists were encouraged and enabled to perform public engagement activities as well as their main research roles.

In parallel to this, the Centre had just been used as a case study project for a student undertaking a Masters in Business Administration. The student had utilised a theory called Complex Adaptive Systems (Herkema 2003) to model the organisation of the Centre, and this theory had proved useful for my thinking about managing a disparate and largely digitally connected group of scientists. I suggested this to my collaborators, and we used the theory to model how the Centre operated from a science communication perspective.

I co-designed the qualitative study which tested this theory, involving semi-structured interviews (*N=14*) with scientists and community partners at all levels of the organisation, including those who were involved in public engagement and those who were not. I did not conduct or analyse the interviews due to being too close to the topic, but I did conduct the literature review for the paper, and edited the final publication.

The study indicated that visible, supportive leadership was critical in order to generate a culture of science communication in an organisation (France et al. 2015). The leader needed to be seen to be undertaking public engagement activities themselves, as well as recognising and rewarding others. Within the theory of Complex Adaptive Systems, this is known as 'tagging', whereby behaviours which you want to replicate are given a name and then held up as an example to the rest of organisation. As an extension of this, a 'fishbowl' is a management technique where a central committee is open in their decision-making and activities, even allowing similar committees to operate aspects of the organisation to

encourage similar behaviours. This network of communication hubs developed spontaneously, but needed nurturing in order to continue their activities. This is where a communications coordinator proved to be critical for the success of the science communication culture; in my role I trained scientists in the skills needed for public engagement, I organised events and communication activities, and I supported relationships between relevant partners. This was quoted by the interviewees as the single most important factor for enabling the Centre to cultivate its public engagement activities and the organisational culture of science communication.

The learning from this study informed all my future publications, and enabled the establishment of the Robots vs Animals project (Publication F) and the Children as Engineers project (Publication H). This publication therefore provides evidence for 1 to 6 inclusive of the UWE Doctoral Descriptors. This paper has an Altmetric of 6, has been cited four times, and has been viewed 188 times on the journal website.

4.5 Science Live - commentary on publication D

> Durant, J., Buckley, N., Comerford, D., **Fogg-Rogers, L.,** Fooshee, J., Lewenstein, B., and Wiehe, B. (2016) Science Live: surveying the landscape of public science events. Project Report. MIT, Cambridge, USA. Available from: http://eprints.uwe.ac.uk/29112

This publication was undertaken in the UK, after I had moved to the University of the West of England, Bristol (UWE) to start work as a Research Fellow in Science Communication. My work on science festivals in New Zealand and the UK led to me being contacted by the teams from the University of Cambridge and the Massachusetts Institute of Technology. The project was stimulated due to a funding call (Science Learning+) from the Wellcome Trust, aiming to establish practitioner and academic collaborations in informal science learning. Science Live was established as an international collaboration to generate deeper understanding of the live science event community. I was recruited into the £70,000 project as the UK Academic Principal Investigator to empirically examine the current environment for live public science events.

The first step within the USA-UK collaboration was to identify and address the conceptual and practical areas of overlap between both countries. The initial area of work involved collaborative agreement about which sorts of live science events we were scoping. Many of the project members came from a science festival background, however, much of the practitioner community worked within smaller-scale science events in communities or schools. As such, the decision was taken to include the whole science event infrastructure and ecosystem, ranging from school outreach events to large science festivals.

I conducted the literature review to scope out what was already known about this field in 2015. The seminal work up to this point was conducted by Bultitude, McDonald, & Custead in 2011, and its key findings still stood the test of time. The science festival community tended to be disconnected from each other, and practitioners were usually professionals from other fields of expertise who were organising science festivals in an amateur capacity. Despite this, the community was growing rapidly and there was much desire from audiences for the expansion of similar events.

Due to the limited amount of science communication academic literature on science festivals and events, I also examined grey evaluation reports and literature from other fields of expertise. Event Management, Arts, and Tourism literature proved to be useful for

understanding how events can be framed as leisure-time learning activities. They also provided much learning about audience motivations and expectations for attending such events. This was incorporated into the final report literature review, and future collaborations with these professions was one of the key recommendations.

I then designed the qualitative research methods, which would enable the project team to interview members of the live science event community. These featured a semi-structured interview schedule for telephone interviews with practitioners and academics, and a semi-structured focus group schedule for group interviews with practitioners. I conducted most (30/33) of the telephone interviews and one of the focus groups. In total, 33 participants were interviewed by telephone in the UK, and 64 participants were included in 11 focus groups at events in the UK and USA.

As we were interested in a baseline assessment of current practice in the community, deeper qualitative methodological analysis was not required. I therefore used thematic analysis (Braun & Clarke 2006) to identify the key themes being discussed by participants, and to look for similarities and differences between the UK and USA, and between different types of event practitioners. These thematic analysis results were incorporated into the final project report which I co-edited. The co-author names are listed alphabetically apart from the Lead Principal Investigator John Durant.

The project findings concluded that live events are as relevant as ever with large audiences, even in a digital age, and they constitute a distinct category of activity (Durant et al. 2016). Many practitioners asserted that events generate new relationships with audiences, and can reshape institutional involvement in science communication. They are in fact ideal to encourage two-way communication within public engagement, as they bring scientists, engineers, and the public physically together. Whilst many practitioners asserted that events have unique learning outcomes, further research was identified as necessary in order to capture the immediate and long-term impacts of event attendance. Indeed, further work would be needed to develop the nascent professional sector, enabling practitioners to learn from research and from each other.

This report was a landscape survey which has paved the way for further research bids and activity as outlined in Section 6.2. The project also continued with a pilot evaluation of science festivals in the UK:

Fogg Rogers, L. and UK Science Festival Network (2017) *UK Science Festival Network Pilot Evaluation 2017.* Project Report. Science Communication Unit, Bristol, UK. Available from: http://eprints.uwe.ac.uk/33602

I have stayed involved with the Science Live team, and following the funded project, we have managed to act on some of the report recommendations. The key developments in the sector have been the establishment of the Science Live practitioner website by the British Science Association: http://www.sciencelive.net/ The British Science Association have also established the UK Science Festival Network, and the Science Events Annual Conference http://sciencefestivals.uk/.

I now act as an advisor to the British Science Association on this topic, and have presented the work at several practitioner events, including:

Fogg-Rogers, L. (2017) Learning to Grow: Evaluation and Reflective Practice. In: *UK Science Festival Network Conference 2017,* Edinburgh, UK, 9 November 2017. Available from: http://eprints.uwe.ac.uk/34401

Fogg-Rogers, L. (2016) Scientists in person: Live science events. In: *Science and Technology Education Group*, London, UK, 20 April 2016. Available from: http://eprints.uwe.ac.uk/29113

Fogg-Rogers, L. and Comerford, D. (2015) Science live phase one: Community scoping and consensus building. In: *British Interactive Group Gathering 2015*, Norfolk, UK, 22-25 July 2015. Available from: http://eprints.uwe.ac.uk/26520

This project and report provide evidence that I meet 1 to 6 inclusive of the UWE Doctoral Descriptors. The report has been downloaded 20 times from the UWE Repository, and has been cited by four others.

4.6 Science communication as impact - commentary on publication E

> **Fogg-Rogers, L**., Grand, A. and Sardo, M. (2015) Beyond dissemination - science communication as impact. *Journal of Science Communication*, 14 (3). C01-CO7. ISSN 1079-6533. Available from: http://eprints.uwe.ac.uk/27106

My work at UWE Bristol involves working with scientists and engineers to consider how they can communicate and engage with the public. Through developing several research projects within UWE Bristol, I gained a tacit understanding of the research landscape in the UK, and the drivers which encourage or discourage public engagement. A key addition to the landscape was the 2014 Research Excellence Framework, which included an assessment of the 'impact' of research beyond academia. The UK Research Councils (RCUK) definition of impact is 'the demonstrable contribution that excellent research makes to society and the economy' (RCUK 2015). The Higher Education Funding Council for England (HEFCE) defined it as 'an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia' (HEFCE 2014).

I and my colleagues, Dr Ann Grand and Dr Margarida Sardo, felt that there were still many questions about whether these definitions encompassed public engagement and science communication case studies. As such, we organised a conference in 2015 in conjunction with the Science in Public network to address the issue of 'Science in Public; Research, Practice, Impact' (Science in Public 2015). The conference attracted an international audience and led to the development of a special issue of the *Journal of Science Communication*.

I led the writing of the introductory journal commentary, critically appraising the culture of impact on science communication projects at present in Europe. I described how the entwining of the concept of impact and the concept of publicly engaged science has the potential to become problematic for researchers. Centrally, we discussed whether public engagement be regarded only as a mechanism for providing evidence of the impact of research or as itself a form of impact (Fogg-Rogers, Grand, et al. 2015).

If engagement becomes more about evaluation and measurement than about altruism, mutual learning, and respect, then as Watermayer (2012, p.120) argues, the potential long-term effect of the definition of impact posited by the Research Excellence Framework could be to transform public engagement from a publicly-focussed activity into the 'engine powering the conceptual, critical and methodological framings and motivations of impact'. Indeed, whilst some institutions have accepted that public engagement can be evidenced as a form of

impact (Terämä et al. 2016), others have reduced the support available for these efforts in favour of more tangible output-driven impact. Over the last three years we have seen these tensions play out more within research contexts, and I believe this will only continue to grow.

This Publication E provides evidence for numbers 1 - 5 of the UWE Doctoral Descriptors. The publication has been cited twice and downloaded 76 times from the UWE Repository.

4.7 Robots vs Animals - commentary on publication F

> **Fogg Rogers, L.,** Sardo, M. and Boushel, C. (2017) Robots vs animals: Establishing a culture of public engagement and female role modelling in engineering higher education. *Science Communication*, 39 (2). pp. 195-220. ISSN 1075-5470. Available from: http://eprints.uwe.ac.uk/30921

While working at UWE Bristol, I drew on my previous experience as a Communications Manager and the learnings from Publication C in order to design a project which would create a culture of public engagement in a research laboratory. Working with Bristol Robotics Laboratory (BRL) and in collaboration with Bristol Zoo Gardens, I designed 'Robots vs Animals', which was funded by the Royal Academy of Engineering in 2014 (£29,500).

The BRL was chosen as it houses over 150 staff in one multi-disciplinary laboratory and yet relatively little public engagement was undertaken at the time of project inception. Robotics is also a topic with much potential for engagement (Laura Grant Associates 2010) and that enables engineering to be presented as a creative problem-solving communal endeavour, as recommended to enhance the perception of girls (Adams et al. 2011; Diekman et al. 2010). I conceived the collaboration with Bristol Zoo Gardens as a way to reach audiences who were not perceived as traditionally interested in engineering. We specifically targeted children aged 11-14 years (particularly girls) and public audiences at non-engineering events.

The project communicated the stories of the engineering design process undertaken by the engineers to create biologically inspired robots. The title was chosen to indicate the playful nature of the collaboration, engendering a spirit of conflict between biomimetic robots and the survival of the fittest animals. In reality, the project featured engineers and zoo educators explaining and demonstrating the skills and processes of their respective charges within one storytelling process. I provided training in storytelling to the engineers and helped the laboratory with their communication and engagement questions. Storytelling is a social and cultural technique designed to present a narrative of events in an arousing way, which aims to capture the audience's attention (Haven 2007). This technique was chosen, as research suggests it can make STEM subjects more approachable, engaging and memorable (Dahlstrom 2014).

Critical to the project development was the recruitment of a Communications Coordinator, Dr Corra Boushel. Corra Boushel planned all the events to my specifications, and maintained communications between all project partners and the engineers throughout the project. We

set up live science events at Bristol Zoo, the local science centre At Bristol, and many other public events and festivals. The events drew on my experience as a Communications Manager in New Zealand, as well as the research I had conducted in Publications A, C, and D.

Drawing upon my research in Publication C about methods to support an organisational culture of public engagement, I recruited five research supervisors into the project to help provide a network of support and leadership for other engineers in the laboratory. The early career engineers were also all recruited into the project at the same time, in order to provide a peer support network. This was aimed at providing social modelling, social persuasion, and vicarious experience opportunities in order to boost their perceived self-efficacy for engineering education outreach (Bandura 2004). Targeted communications were directed at female engineers in particular, in order to purposively create gender balance in the presenters. All the events featured two engineers presenting together; this has been shown to be effective in facilitating paired peer knowledge exchange in order to enable mastery of communication and storytelling techniques (Fogg-Rogers, Lewis & Edmonds 2017). The engineers were also invited to watch the experienced research supervisors undertaking public engagement at live public science events in order to provide further opportunities for vicarious experience (Bandura 2004).

A quasi-experimental design was employed to evaluate the impacts of the project, with mixed methods data gathered at pre- and post-project time points. I organised all the data collection methods and organised the project timetable. The early career engineers completed a questionnaire before participating in the project, which collected demographic data and assessed their prior experience of public engagement and motivations for involvement. Self-efficacy was measured before and after their participation in the project using the Education Outreach Self-Efficacy Scale (EOSS), which I have since validated in Publication I. I employed descriptive and analytic statistics to analyse the data, comparing results over time (before and after) and between male and female groups.

Semi-structured interviews were conducted by Dr Margarida Sardo at the end of the project, with the research supervisors and the early career engineers answering questions about their previous public engagement activity, their reactions to this project, and their thoughts on supporting public engagement through organisational cultures. I designed the interview schedule, and also undertook qualitative thematic analysis of the interview transcripts.

The quantitative project results indicated that the engineers positively reviewed the programme, and their Engineering Outreach Self-efficacy significantly increased over the

course of the project (Fogg-Rogers, Sardo & Boushel 2017). Qualitative results indicated that training in storytelling was useful, as was a supportive peer group for public engagement. Critical to the project success was the science communication coordinator (Corra Boushel) who could help the researchers organise public engagement and support their development. This reinforced my own experience as a communications coordinator, and the research outcomes from Publication C. It also reinforced my ideas that behaviour and culture change approaches supported by social cognitive theory can be successfully applied to public engagement activities and higher education environments.

However, the issue of purposive recruitment of female engineers (in order to generate a gender balance amongst live event presenters) proved controversial for some male engineers (Fogg-Rogers, Sardo & Boushel 2017). They reasoned that selecting women as presenters created unfair barriers for men who wished to participate in public engagement, as well as being unnecessary because science is gender-neutral. However, I argued that purposive recruitment in male-dominated fields is incredibly important to normalise female role models in STEM and also to broaden implicit societal messaging about which careers are appropriate for girls. It must, however, be acknowledged that there is a conflict to be managed so that these activities do not become overly burdensome for female engineers and more importantly, they should be properly rewarded through funding or promotion procedures. Furthermore, in response to criticism that boys or men will be disadvantaged by 'positive discrimination' against them, I highlighted research that indicates that boys are not 'put off' by seeing female role models in male-dominated sectors (Lockwood 2006; Carrington & McPhee 2008).

I wrote up this research into a project report which was presented back to the Royal Academy of Engineering:

> Fogg-Rogers, L., Sardo, M., and Boushel, C. (2015) *Robots vs animals: Learning from the ingenuity of nature. Final summary report.* Project Report. Royal Academy of Engineering. Available from: http://eprints.uwe.ac.uk/26062

I also presented the work at two conferences:

> Fogg-Rogers, L., Sardo, M. and Boushel, C. (2015) Emotional engineering – the story of Robots vs Animals. In: *Stories about Science: Exploring Science Communication and Entertainment Media*, Manchester, June 4-5 2015. Available from: http://eprints.uwe.ac.uk/25832
>
> Fogg Rogers, L. (2017) Robots vs animals: Cultures of public engagement. In: *Engage 2017*, Bristol, UK, 6-7 December 2017. Available from: http://eprints.uwe.ac.uk/34403

I wrote the final Publication F which is listed in this DPhil, and my co-authors edited the manuscript. This project and final publication provide evidence for 1 to 6 inclusive of the UWE Doctoral Descriptors. The publication has been downloaded 176 times from the journal website, downloaded 117 times from the UWE Repository, and has an Altmetric of 20. The project has informed much of my later work, which I will discuss in Publications G and I, as well as the impact of my research in Section 6.

4.8 Women in science and engineering - commentary on publication G

> **Fogg-Rogers, L.** (2017) Does being human influence science and technology? *Journal of Science Communication*, 16 (4). Available from: http://eprints.uwe.ac.uk/32954

Through my work on Robots vs Animals, I started to be asked to take part in discussions and presentations about women in STEM careers. I became involved in the Committee for UWE Bristol's Women Researchers Mentoring Scheme, as well as the Athena Swan Committee for the Department of Engineering Design and Mathematics. This experience led me to develop my argument about why we should attempt to encourage more girls and women into STEM. I presented this work at two conferences:

> Fogg Rogers, L. (2017) People like me do that – and it's okay! In: *Hypatia Network Hub 2017*, Bristol, UK, 8 March 2017. Bristol, UK Available from: http://eprints.uwe.ac.uk/31583

> Fogg Rogers, L. and Boushel, C. (2017) Are women part of mankind? Vicarious experience and self-efficacy. In: *Science in Public: How do science and technology affect what it means to be human?* Sheffield, England, 8-10 July 2017. Available from: http://eprints.uwe.ac.uk/32643

In late 2017, I was asked to develop these presentations into a Commentary for the *Journal of Science Communication*. I drew on Social Cognitive Theory to explain why vicarious experience is important for girls and women; if we wish to influence whether it is considered socially acceptable for women to take part in STEM, we need to change the representation of STEM, scientists, and engineers in all aspects of society (Fogg-Rogers 2017b). This includes our use of language, the images we use in public engagement, and the presenters who discuss science in our media or events. Fundamentally, if girls don't see women being received positively in STEM roles, then they will never think that STEM is a 'normal' thing for women to do.

I also gave three arguments for why we should try to increase the numbers of women in STEM careers:

- Utilitarian - STEM careers urgently need more workers in order to secure the economic future of developed countries. If only 50% of the population are attracted to a profession, then there is a further 50% of the population which may prove to be a new recruitment pool.

- Equity - if we accept that women have to face different challenges in life due to their biology and societal expectations, then workplaces and employers should be able to accommodate these issues and the diversity amongst their employees.
- Democratic - if women are not at the table, then 50% of the population is not represented in decision-making for our society. Women bring different life experiences and new approaches to problems and solutions in STEM. Encouraging diversity in all its forms, including race and social class, means that we can deliver collaborative solutions which work for the majority of our society.

Through this commentary I developed some 'top tips' for practitioners for simple ways they can involve a diversity of presenters and professionals in their public engagement. This was disseminated in a blog post and an Events Guide on the Science Communication Unit website.

> Fogg-Rogers, L. (2017). Are women part of mankind? *Science Communication Unit Blog*. Available at: https://blogs.uwe.ac.uk/science-communication/are-women-part-of-mankind/.
>
> Fogg-Rogers, L. and Boushel, C. (2017). *Event Public Engagement Guide*, Available at: http://www1.uwe.ac.uk/research/sciencecommunicationunit/coursesandtraining/practitionerguides.aspx.

This Publication G provides evidence for numbers 2 and 5 of the UWE Doctoral Descriptors. The publication has been downloaded 24 times from the UWE Repository.

4.9 Children as Engineers - commentary on publication H

> **Fogg-Rogers, L.,** Edmonds, J., and Lewis, F. (2017). Paired peer learning through engineering education outreach. *European Journal of Engineering Education*, 42 (1). pp. 75-90. ISSN 0304-3797. Available from: http://eprints.uwe.ac.uk/29111

Alongside my work on Robots vs Animals (F), I also developed a collaboration through the Department of Education at UWE Bristol with Dr Fay Lewis and Juliet Edmonds. Given that teachers have a huge influence on the perceptions and attitudes of children towards STEM, it made sense to consider how teachers present science in the classroom. In the UK only 5% of primary teachers have a science-related degree (Department for Education 2013) leading to concerns over teachers' science subject knowledge, particularly in the physical sciences (Murphy & Whitelegg 2006; Royal Society 2010). Although subject knowledge is not seen as essential for effective pedagogy, a lack of confidence and understanding can result in didactic, traditional, and 'cautious' teaching (Neale et al. 1990) as teachers do not feel comfortable when teaching STEM subjects (Bleicher & Lindgren 2005). Conversely, improvements in teachers' attitudes to a subject can lead to a positive impact not only on children's performance but also on their engagement and enjoyment (Ofsted 2011). This highlights the importance of addressing and positively influencing pre-service teachers by cultivating positive dispositions and beliefs towards subjects such as science and engineering during their training.

This collaboration developed into the project 'Children as Engineers', which was funded by the Engineering Professors' Council (£9,500) in 2014 and subsequently by HEFCE (£49,500) in 2016. I wrote both bids, and have designed and project managed the training, delivery, and research since its inception. We aimed to test a new model of training and experience for undergraduate curricula; pairing student engineers (BEng and MEng) and pre-service teachers (Initial Teacher Education – BA Education) to mentor each other to deliver engineering education outreach activities in schools. Initially, the project involved volunteer students, but we have since managed to embed the model within degree structures so that students receive academic credits for taking part in the projects.

In 2014 the project involved 11 student engineers and 10 pre-service teachers, working with four local primary schools and ten classes of children (269 children). The aim was for the engineers to mentor and improve the pre-service teachers' subject knowledge confidence and perceived self-efficacy (PSE) for STEM subjects, while the pre-service teachers would mentor and improve engineering students' public engagement and communication skills, along with

their PSE for engineering outreach. Through delivery into primary schools, the intervention aimed to improve attitudes and attainment in STEM for young children aged 8-11 years, ultimately aiming to improve the age and gender mix of those participating in engineering.

This intervention utilised the EU ENGINEER design challenges which are freely available on the project website (ENGINEER 2015), and have been tested as being inspiring for primary school children to work on. I provided training for the student engineers about public engagement and communication skills, while my colleagues provided training in inquiry-based science education. The pre-service teachers were trained in the engineering design process, and also provided with the curriculum packs for the ENGINEER Challenges. The students were then paired up to work on their lesson plans to go into schools. Over the course of a three week period, the students prepared their education outreach activities and then delivered this in schools.

I led the design of the project evaluation, using a quasi-experimental mixed methods design, with data triangulated from the three participant groups (student engineers, pre-service teachers, and children). Juliet Edmonds led the data collection from children, Fay Lewis led the data collection from the teachers, and I led the evaluation of the engineers' experience. I designed and administered a pre- and post-project questionnaire to ascertain the demographic particulars, prior experience, and attitudes of the engineers towards public engagement, and latterly towards the project experience. The engineers also completed my EOSS questionnaire before and after the project, to assess whether their PSE for engineering education outreach had changed. Finally, qualitative data were collected through reflective diaries which the engineers filled out throughout the project.

I conducted the data analysis for both the quantitative and qualitative data from the engineers. The questionnaires and EOSS scale were analysed using descriptive and analytic statistics. I also conducted a qualitative thematic analysis (Braun & Clarke 2006) on the engineers' and teachers' comments from the open questions and reflective diaries. Using a process of inter-coder constant comparison (with Fay Lewis), the responses from the pre-service teachers and student engineers were triangulated into one coding frame.

Both the engineers and teachers reviewed the project positively (Fogg-Rogers, Lewis & Edmonds 2017). The quantitative data indicated that working in a partnership was rated as one of the most rewarding aspects of the project, and qualitative data reinforced this with multiple assertions that the paired peer mentoring enabled active learning between the partners. The student engineers qualitatively stated that they had learnt a lot about teamwork

and communication through participation in these hand-on activities. An unexpected benefit was also found in communicating disciplinary engineering concepts to less knowledgeable audiences, as the engineers indicated that it actually consolidated their own learning. The engineers also showed an improvement in their perceived level of skills, with a 42% increase in the proportion who felt they were now 'fairly well equipped' to undertake public engagement; over two-thirds (64%) of the engineers gave this rating following the project. However, their PSE for engineering education outreach did not significantly increase over the course of the project. This is in contrast to my work on Robots vs Animals, possibly due to the short duration of Children as Engineers.

Interestingly, there were highly significant increases in the pre-service teachers' engineering subject knowledge confidence levels as well as their PSE for teaching engineering following the intervention. Bandura (1997) suggests that PSE may be most amenable to change during early learning; indicating that teachers' beliefs and PSE are therefore potentially the most susceptible to influence and change during their initial training (Flores & Day 2006). Participating in this intervention early in a teaching career could be crucial in shaping dispositions towards STEM subjects and engineering careers in the future; with improved PSE and subject knowledge being linked to improved teacher performance (Bates et al. 2011; Mcmullan et al. 2012). We have since pursued this line of inquiry and I will discuss this further in the Impact section of this DPhil Commentary.

I wrote up the project into a report for the Engineering Professors' Council:

> Fogg-Rogers, L., Edmonds, J., and Lewis, F. (2015). *Children as engineers: Paired peer mentors in primary schools final report summary July 2015.* Project Report. Engineering Professors' Council. Available from: http://eprints.uwe.ac.uk/26053

We have also presented the research at several conferences:

> Fogg-Rogers, L., Hobbs, C., Edmonds, J. and Lewis, F. (2015) Children as engineers: Maximising engineering outreach for universities. In: *Engineering Professors' Council Congress 2015*, Salford, April 15 2015. Available from: http://eprints.uwe.ac.uk/25833

> Lewis, F., Edmonds, J. and Fogg-Rogers, L. (2015) Primary pre-service teachers and engineering students learning to teach science - A match made in heaven or

hell? In: *European Conference on Educational Research (ECER)*, Budapest, Hungary, 8-11 September 2015. Available from: http://eprints.uwe.ac.uk/27182

Fogg Rogers, L., Edmonds, J. and Lewis, F. (2017) Curiosity connections – paired peer learning between engineers and teachers. In: *Beyond STEM - Informal science learning across disciplines*, London, England, 19 May 2017. Available from: http://eprints.uwe.ac.uk/32642

Fogg Rogers, L. and Fowles-Sweet, W. (2017) Engineering and society: Embedding active service learning in undergraduate curricula. In: *Unibility: Conference on University Social Responsibility*, Barcelona, Spain, 22 September 2017. Available from: http://eprints.uwe.ac.uk/33502

Fogg Rogers, L. and Fowles-Sweet, W. (2017) Engineering and society: Embedding active service learning in undergraduate curricula. In: *The UK and Ireland Engineering Education Research Network: Time for change! Challenging the status quo in engineering education,* London, UK, 24 November 2017. Available from: http://eprints.uwe.ac.uk/35000

I wrote the final Publication H which is listed in this DPhil, and my co-authors edited the manuscript. This project and publication provides evidence that I meet 1 to 6 inclusive of the UWE Doctoral Descriptors. This publication has been cited twice, viewed 226 times on the journal website and has been downloaded 36 times from the UWE Repository.

4.10 Validating the Engineering Outreach Self-efficacy Scale - commentary on publication I

> **Fogg-Rogers, L.,** and Moss, T. (2018) Validating a scale to understand engineers perceived self-efficacy for engineering education outreach. Submitted to *Learning and Individual Differences*.

My work on Robots vs Animals (F) and Children as Engineers (H) led to the development of the Engineering Outreach Self-efficacy Scale (EOSS), which was used to generate results in both projects and Publications F and H. Research evidence suggests that providing scientists and engineers with training programmes and structured experience can boost perceived self-efficacy (PSE) to perform education outreach, which in turn means better quality and more frequent public engagement. I decided to design a scale to measure engineers' PSE for education outreach activities in order to enhance research into science communication training and practice. However, the scale had not been tested in a psychologically valid format in order to confirm its validity as a latent construct, which ran in contrast to recent reviews urging for more construct validity testing in psychology (Flake et al. 2017). I therefore worked with my DPhil supervisor Dr Tim Moss in order to design a study which would ensure the validity and reliability of this scale for use in future projects.

The construct of EOSS was influenced by my experience running training for education outreach, as well as concepts outlined in the literature, describing the skills and challenges that can be perceived in the context of engineering education outreach. The questions were reviewed by experienced engineering outreach practitioners to ensure content relevance and representativeness. The instrument uses a 10-point Likert scale ranging from Not at All Confident in the ability to perform the item, to Totally Confident in the item. However, numbers represent the scale rather than words, as Bandura advises this wide range of options offers more discriminatory scalar analysis (Bandura 2006). The wording of the questions was influenced by similar scales accessing PSE, in particular the Teaching Engineering Self-efficacy Scale (TESS) (Yoon Yoon et al. 2014).

Two sub-samples of engineers were recruited to test the scale for internal and external reliability and validity. A group of undergraduate students (*N=38*) taking the new module Engineering and Society (developed from the Children as Engineers project; see Section 6.3) completed a paper-based version of the questionnaire in September 2017 and again in December 2017. Professional engineers who had undertaken engineering education outreach

(*N=39*) were also invited to complete a web-based version of the questionnaire (using Bristol Online Surveys) between September and November 2017.

The participants completed a questionnaire which featured the EOSS questions, but also included two other scales for convergent and discriminant validity analysis. The National Institutes of Health Toolbox v2.0 scale for Self-Efficacy (in 18+ adults) (National Institutes for Health and Northwestern University 2016) was included to measure general PSE, which we hypothesised would correlate with the EOSS. To test for discriminant validity we included the Mini-IPIP, which is a validated 20-item short form version of the International Personality Item Pool, which assesses the Big Five Factor Model of personality including Openness/Imagination, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Donnellan et al. 2006).

I designed the questionnaire, conducted the research, and also conducted the descriptive statistics in Microsoft Excel. My supervisor Dr Tim Moss advised on the analytic statistics, and I conducted these in SPSS v24. The internal validity tests indicated that the EOSS has structural integrity, with a full range of responses selected, and a high reliability for use, with Cronbach's coefficient alpha $\alpha = .91$. The EOSS has good convergent validity, with a significant positive correlation to the NIH Toolbox Self-Efficacy scale as hypothesised. The EOSS also has good discriminant validity, with no significant correlations to personality factors on the Mini IPIP, apart from Openness/Imagination. Initial small-scale test-retest use indicated that the scale has the potential to discriminate change over time, as it detected a significant improvement in PSE for engineering outreach following training and experience.

Evidence suggests that training programmes and structured experience can boost perceived self-efficacy for engineering education outreach, which in turn means that engineers may take part in better quality and more frequent public engagement. Measuring engineering outreach PSE provides a way to evaluate the impact of outreach training programmes, and as such, I hope this scale will prove valuable to researchers and participants. I wrote the final Publication I describing this process, which is currently under review in an open access journal. This provides evidence that I meet 1 to 6 inclusive of the UWE Doctoral Descriptors.

5. Methodological Considerations

My research practice and epistemological position inherently reflects the fact that I was a practitioner first and foremost before conducting any research. My work sits in a critical realist paradigm and draws on a pragmatic approach to research. As such, the methods utilised in each paper vary to fit the research aims of the project and to suit the participants involved.

The following sections examine each of the UWE Doctoral Descriptors in turn, to reflect on how my publications meet these requirements. As such, the descriptors are listed here in full for consideration:

1. Has conducted enquiry leading to the creation and interpretation of new knowledge through original research or other advanced scholarship, shown by satisfying scholarly review by accomplished and recognised scholars in the field;
2. Can demonstrate a critical understanding of the current state of knowledge in that field of theory and/or practice;
3. Shows the ability to conceptualise, design and implement a project for the generation of new knowledge at the forefront of the discipline or field of practice including the capacity to adjust the project design in the light of emergent issues and understandings;
4. Can demonstrate a critical understanding of the methodology of enquiry;
5. Has developed independent judgement of issues and ideas in the field of research and/or practice and is able to communicate and justify that judgement to appropriate audiences;
6. Can critically reflect on his/her work and evaluate its strengths and weaknesses including understanding validation procedures.

5.1 Original research and advanced scholarship

All nine of the publications listed in this DPhil demonstrate my ability to produce original research and advanced scholarship. Eight of the publications (A-C; E-I) have been peer reviewed in international journals, which demonstrate that this work satisfies the criteria of scholarly review by accomplished and recognised scholars in the field. Seven of the publications (A-D, F, H, I) describe the outcomes of original research projects which I either co-designed or entirely conceptualised, which will be discussed further in Section 5.4. Two of the publications (E, G) are commentaries in which I demonstrate advanced scholarship to discuss current research and practice in science communication.

My approach to research means that I situate a research question within a live societal context, involving real community partners and human participants. This means that the research environment is complex and changes throughout the project. As such, I have found that transdisciplinary collaboration is key to develop and sustain these projects within real life situations. As such, eight of my publications (A-F, H, I) involve other authors named as collaborators. Three of my publications were led by other people, although I played a critical role and demonstrated other elements of the UWE Doctoral Descriptors. However, I led the design, management and write-up of five of my publications (A, E-I), which is why I am listed as first author on those publications.

5.2 Critical understanding of science communication theory and practice

In eight of my publications (A, C-I), I either led or contributed to the writing of the final paper. This involved conducting several literature searches in order to contextualise the research project within the current academic and theoretical environment. As my work involves conducting research on live science communication projects, a transdisciplinary collaborative approach has been essential. Consequently, I have gained experience in reviewing literature from the fields of science communication, science education, health communication, event tourism, and social psychology. This has meant that I have developed a critical understanding of several fields of research, and I am able to apply this to science communication theory and practice.

5.3 Conceptualising, designing and implementing a project

Seven of my publications have arisen from original research projects (A-D, F, H, I), which I either co-designed or entirely conceptualised. As my commentaries (E, G) involved a critical review of current practice in the field, they did not originate from a single research project. Through my research projects, I have developed excellent project management skills, and the ability to develop and pitch a project in order to get it funded externally.

Three of the projects I have worked on were led by other people who are named as first author on the publications (B, C, D). However, I played a critical role in the conceptualisation of each project, ensuring that science communication theory was applied to the research questions and project design, and that the research methods would work within real life contexts.

I project managed the lifespan of four of my projects and publications (A, F, H, I). This involved bid writing for funding, developing the project timeline and objectives, managing the research process and deliverables, and finally academic and public dissemination. This means I am experienced at making day-to-day decisions about my own work as well as managing colleagues to direct their research outcomes in order to work towards long-term collaborative goals and deadlines.

I have participated in several programmes to develop my leadership skills through the UWE Researcher Skills Development Programme, and the UWE Manager courses. In 2015 I was selected to participate as one of UWE's delegates on the Vitae South West Preparing for Leadership course. Alongside this, in 2015 I was selected to participate in the UWE Women Researchers Mentoring Scheme, and have since gone on to become a member of the organising committee from 2017 onwards.

Through this experience and training, I created the project plans which resulted in publications A, F, H, and I. This consisted of designing work packages and Gantt charts, designing workloads for newly employed staff, generating cost estimates for project implementation, and finally managing budgets and signing off research spending. These four projects actually ran in parallel, indicating that I am capable of managing several projects at once to ensure that all projects remain on track within budget and timescale. I am therefore experienced at helping team members remain aware of project timescales and deliverables, and providing support or training where it is needed to mentor colleagues.

5.4 Critical understanding of the methodology of enquiry

I have applied different research methods within each research project and for each publication, as indicated in Table 2. I consider myself to be capable with many methods of social psychological research, however my breadth of knowledge does mean that I am not an expert in any one particular type. Whilst this may be a disadvantage in some fields, it is actually an advantage with the kind of pragmatic mixed methods research I have been undertaking. I am able to collaborate with many types of researchers from different disciplines, and I can apply my knowledge practically according to the participants and research questions needed.

I am experienced at purposive and cross-sectional sampling of participants for qualitative research. I have become skilled at designing, conducting and analysing qualitative research from semi-structured interviews, snapshot interviews, focus group research, observations and open questions on questionnaires. Due to the pragmatic design of my research studies, and the time-bound nature of live science events, I have not been able to experience sampling participants until saturation is reached, or conducting a deep ethnographic exploration of participants' lives. Similarly, while I am experienced at thematic analysis and content analysis using NVivo in order to generate inductive or deductive themes, I have not experienced other more in depth qualitative methods such as Interpretive Phenomenological Analysis. This is inherent within the nature of pragmatic research designs conducted in critical realist paradigms, where the gold standard for qualitative research may be compromised in order to meet the needs of the live science event, including funder, practitioner, or audience needs.

Through my projects, I have also become experienced at quantitative questionnaire design, administration (in paper or online formats), and analysis, as well as designing and validating a new psychological construct and scale. I am experienced at conducting and presenting descriptive statistics using Excel. I also have a working knowledge of parametric and non-parametric analytical statistics using SPSS. However, due to the nature of conducting research on live science events with limited funding, I have not been able to develop a large-scale, longitudinal quantitative study. While my publications have shown statistical significance, they would not meet the gold standards for quantitative research as they have not shown randomisation, high power, and large effect sizes. This is the compromise involved in real-world pragmatic research involving live events and audiences who do not necessarily want to be long-term research subjects.

Table 2: Research methods and sampling employed within each publication submitted as part of this DPhil.

Paper	**Doctoral Descriptors**	**Methods conducted by Laura Fogg-Rogers**
A) Evaluation of Brain Day Auckland http://eprints.uwe.ac.uk/25328	1,2,3,4,5,6	• Cross-sectional mixed methods paper-based survey, conducted over three years at a health research science festival. Public attendees at the festival self-selected to participate. • Qualitative methods: - Open questionnaire responses with 661 participants - Thematic Analysis • Quantitative methods of inquiry: - Likert and rank list questions on questionnaire with 661 participants - Descriptive statistics for whole sample, sub-samples per year, and for gender, age group, education level and ethnic background. - Analytic statistics to compare annual sub-samples and demographics characteristics using non-parametric Kruskal-Wallis, Wilcoxon Signed Ranks, cross-tabulation, multinomial regression, Spearman correlation, and parametric Pearson correlation tests.
B) Māori Stroke Awareness http://eprints.uwe.ac.uk/24599	1,3,4,5	• Cross-sectional snapshot qualitative oral interviews. 850 participants were purposively recruited outside shopping malls by research assistants. • Content analysis conducted by other authors.
C) Cultures of Science Communication http://eprints.uwe.ac.uk/27481	1,2,3,4,5,6	• Qualitative semi-structured interview design • 14 members of the Centre for Brain Research purposively recruited. • Thematic analysis conducted by other authors.
D) Science Live http://eprints.uwe.ac.uk/29112	1,2,3,4,5,6	• Qualitative semi-structured interview design

		• Science communication practitioners were purposively recruited to participate. • Semi-structured interviews with 33 participants. • Focus groups with 64 participants. • Thematic Analysis triangulating interviews and focus groups.
E) Science Communication as Impact http://eprints.uwe.ac.uk/27106	1,2,5	N/A
F) Robots vs Animals http://eprints.uwe.ac.uk/30921	1,2,3,4,5,6	• Mixed methods pre and post evaluation of the project with 15 purposively selected engineers. • Qualitative methods: - Semi-structured interview design with 15 participants. - Open questionnaire responses with 10 participants. - Thematic Analysis triangulating interviews and questionnaires • Quantitative methods: - Likert and rank list questions on questionnaire with 10 participants. - Design of EOSS self-efficacy scale - Descriptive statistics - Pre and post analytic statistics for EOSS self-efficacy scale using non-parametric Wilcoxon Signed Ranks Test and Mann-Whitney U Test.
G) Women in Science and Engineering http://eprints.uwe.ac.uk/32954	1,2,5	N/A
H) Children as Engineers http://eprints.uwe.ac.uk/29111	1,2,3,4,5,6	• Mixed methods pre and post evaluation of the project with 11 purposively selected engineers. • Mixed methods pre and post evaluation of the project with 10 purposively selected teachers, conducted by other authors.

		• Qualitative methods: - Reflective diaries and open questionnaire responses with 21 participants. - Thematic Analysis triangulating diaries and questionnaires. • Quantitative methods of inquiry: - Likert and rank list questions on engineers' questionnaire analysed using descriptive statistics. - Pre and post analytic statistics comparing engineers' and teachers' questionnaire responses using the non-parametric Mann-Whitney U Test. - Pre and post analytic statistics for EOSS self-efficacy scale, using non-parametric Wilcoxon Signed Ranks Test.
I) Validating the EOSS	1,2,3,4,5,6	• Design and validation of the standardised EOSS 10-item self-efficacy scale. • Paper-based questionnaire with 38 university students. • Online questionnaire with 39 self-selecting professional engineers who undertake education outreach. • Descriptive statistics for EOSS and comparative Mini-IPIP and General Self-efficacy scales. • Analytic statistics to compare professional/student sub-samples and gender, as well as between scales, using parametric ANOVA, Pearson's correlation and paired T-tests.

5.5 Independent judgement and communication of issues

I am highly experienced at communicating research in multiple formats and to multiple audiences, and this is evidenced in all my publications (A-I). I am also skilled at keeping external stakeholders engaged with regular updates to project progress and outcomes. I am confident communicating my own research in academic formats such as conferences, journals, reports, and meetings as outlined in Section 4. I also have a deep understanding of communicating with different audiences through organising live science events. This has enabled me to develop independent judgement in designing, funding and implementing my own research projects, as outlined in Section 5. 3.

I regularly communicate my own work, as well as updates in the field, through social media. I am active on my Twitter account with over 860 followers (@laurafoggrogers) as well as designing the communication strategies for my project communications including @RobotsvsAnimals, @BrisPrimSTEM and @ClairCity. I am experienced at public speaking and designing activities for a variety of audiences, including children, students and adults. I also contribute to the Science Communication Unit Blog.

5.6 Critical reflection on research

In all seven of my publications arising from original projects (A-D, F, H, I), I have had to critically reflect on the novel aspects of the work, as well as the limitations within the study. These publications have been peer reviewed and published in international journals, which demonstrates that I can critically reflect on my work to a standard suitable for scholarly activity. In this section, I have taken the opportunity to critically reflect on my epistemological position; developing pragmatic research projects which are situated within real life contexts, namely live science events.

I prefer a mixed methods approach to research, as this enables the research question to be examined from several different angles, along with the triangulation of results between participants and from different perspectives (Denscombe 2010a). Quantitative data is useful in a market environment which demands to see a return on investment; including statistics about the outputs and reach of science communication projects are necessary to justify the impact of the engagement to funders. This form of enquiry sits within a more positivist paradigm, accepting that there is a truth to be found, and that research enquiry will enable us to get closer to this understanding.

However, descriptive and analytical statistics do not allow an in depth exploration of phenomena from the point of the view of the participants, and as such, only reflect what *is* happening, and not *why* it is happening. Qualitative data allows a deeper understanding of a subjective truth; which reflects a worldview unique to participants and relative to the worldview of the researcher. I enjoy examining qualitative data, as it provides insights into phenonomena which I could not have imagined without talking to participants, and it also demands reflexive and critical thought from myself as a researcher. However, qualitative data on its own is usually not enough to justify change in practice or funding.

Social psychology research methods are therefore well suited to science communication practice, as they enable a breadth of examination which can be adapted to suit each particular circumstance. Through triangulating quantitative and qualitative data from a variety of perspectives, we can approach a truth which can be socially constructed and agreed upon by all involved. This pragmatic approach to research is then well suited to understanding and changing practice within a societal context, which is my ultimate aim.

6. Contribution to Impact and Continuing Work

Through undertaking the studies outlined in this DPhil, I have enabled the growth of the outreach and public engagement cultures at two universities on opposite sides of the world.

6.1 Centre for Brain Research, University of Auckland

As a practitioner and researcher at the University of Auckland, I put in place several engagement and involvement schemes that are still running at the Centre for Brain Research (Centre for Brain Research 2014), such as the Community Partners scheme, Māori Advisory Board, Research Volunteer Register, Clinical-Research Seminars, the BrainWaves young researchers group, and the CBR Connections newsletter. Indeed, the teams have cited my work as instrumental to the establishment of the Centre and to the community involvement practices which generate the ethos of the Centre. I am still in touch with my former colleagues in New Zealand, and they keep me updated on how the extensions to these projects have developed.

6.2 Live Events and UWE BoxED

Within UWE Bristol, and more widely across the West of England, I have contributed towards the development of a sustainable culture of public engagement. Robots vs Animals (F) led to several public engagement events, media opportunities, and outreach events for the Bristol Robotics Laboratory, the largest research centre in robotics in the UK. Following the success of the project, working with UWE Research Business and Innovation has enabled the BRL to undertake more public engagement work, alongside an ongoing programme to train new PhD students as STEM ambassadors every year in collaboration with the FARSCOPE PhD training scheme (http://www.brl.ac.uk/publicengagement.aspx). The BRL now has strong links with We The Curious science centre, and myself and the collaborators on the project were consultants on two major new exhibitions in At Bristol called 'Robot Encounters' and the 'Tinkering Space' (https://www.wethecurious.org/event/robot-encounters-summer), reaching 300,000 visitors in 2016/2017.

The employment of Dr Corra Boushel as a coordinator on Robots vs Animals also enabled work on a wider culture of engagement in UWE Bristol through the establishment of the Faculty of Environment and Technology (FET) Public Engagement and Outreach Awards, and the

development of the 'FET in a Box' project to translate UWE research into outreach programmes for local schools. The success of the FET in a Box project was picked up by UWE Widening Participation, and translated into 'UWE BoxED', which is now the major vehicle for all schools work across UWE (https://youtu.be/HyfUnr4bgpY; http://www1.uwe.ac.uk/study/schoolsandcolleges/uweboxed.aspx). I continue to be Corra's line manager and we are collaborating together on several public engagement projects.

My work on the Science Live project means that I am also an advisor to several groups on organising live events. In particular, I have attended several meetings of the UK Science Festival Network and the British Science Association in order to contribute to strategy developments. I developed a pilot evaluation strategy for UK festivals in 2017, and I hope to develop this further through applying for further grant funding in the near future.

6.3 Engineering and Society

The Children as Engineers (publication H) model has now been incorporated as a credit-bearing module in the UWE Initial Teacher Education BA degree by Dr Fay Lewis and Juliet Edmonds. Through my HEFCE funding, I have also gone through the UWE Curriculum Approval Process to design a Level 6 third year Module for BEng/MEng students in Engineering. The module was developed with my engineering colleague Wendy Fowles-Sweet and is called 'Engineering and Society', providing experience of becoming a professional engineer within societal contexts. In 2017/2018 we worked with 35 pre-service teachers, 45 student engineers, and 960 primary school children. Establishing the paired peer model within the university system has meant that we are able to provide proper credit and recognition for outreach and engagement for students. This means that it is now perceived as a worthy activity amongst our colleagues, and enables the activity to continue with less administrative barriers.

6.4 Curiosity Connections Bristol

My HEFCE funding also enabled me to establish the Curiosity Connections Bristol network, which brings together science communicators and industries undertaking outreach with primary schools alongside primary school teachers and the education community (https://curiositybristol.net/). The network is billed as being the hub for anyone interested in inspirational primary STEM education in the Bristol region. The Advisory Board includes

representatives from UWE Bristol, the University of Bristol, Bristol City Council, Tomorrow's Engineers, the Ministry of Defence, and STEM Ambassadors West of England. It connects teachers and STEM Ambassadors in order to share best practice and events to promote STEM activities which aim to inspire young children.

I established the network to help support primary STEM engagement in a difficult market environment. Primary STEM public engagement is becoming difficult to justify in a Higher Education environment, which emphasises return on investment and direct recruitment of young people to university. This is despite my own research, and the multitude of reports which concur, indicating that attitudes to STEM are formed before the age of 11, and in particular for girls whose gender identity plays a critical role in their subject and career choices. It has therefore become vitally important for this area of work to be championed against market forces, and for the current providers and ambassadors to be supported to continue their work.

6.5 ClairCity

Another project which was established in parallel to this DPhil, was the EU project ClairCity (www.claircity.eu). I am the Communications Manager (Work Package Lead for Dissemination and Ethics) for this consortium, and my colleague Dr Corra Boushel is now the Communications Coordinator on this project. The project launched in 2016 and aims to raise awareness of air pollution, carbon emissions and health in cities, and to engage thousands of citizens with the decision-making process for future city life. I designed the Communications, Evaluation, and Ethics strategies for this project. My research on all the Publications in this DPhil have given me the knowledge and skills in order to advise a Consortium of 16 partners across 12 countries about ethical recruitment of participants, public engagement strategies, communication and media campaigns, and evaluation of impact.

In particular, the learnings from Publications A, B and D have driven my communications strategy for engagement at live science events. As well as traditional methods of public engagement through science festivals, science centres, and social media, we have also been seeking to reach people who do not traditionally engage with scientific issues. This has seen our project team taking the engagement activities out to community festivals, local interest groups and deprived neighbourhoods; and we have been successful in reaching people from diverse demographics who would not otherwise be engaged. This has been a particular

success from my DPhil, and I have now also instilled this drive for wider engagement within our scientific project collaborators.

6.6 Training for science communicators and researchers

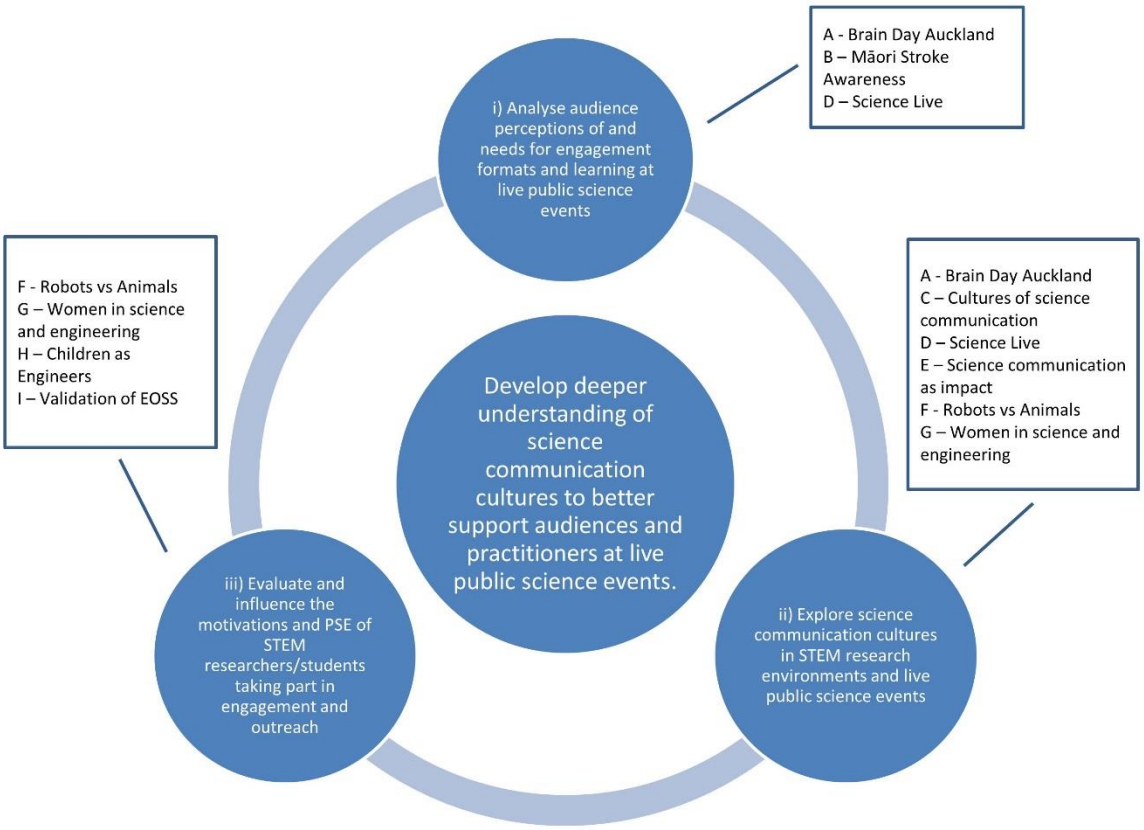
Training and teaching have featured heavily throughout my time at UWE Bristol. I teach over 100 students each year through the Science Communication Unit's links to several undergraduate BSc programmes across the University. I helped to establish and market the SCU Online Course in Science Communication. This innovative online course is internationally available, and supports the learning of distance students from all over the world. I also provide internal and external training courses in public engagement for STEM researchers, reaching around 50 researchers each year. I have supervised nine MSc student projects and supported the students' dissertations and marking.

My scholarship in the field of science communication means that I am now asked to review papers for journals such as the European Journal of Engineering Education and F1000, alongside being a grant reviewer for the Wellcome Trust and the Royal Academy of Engineering. I am a member of the Science in Public network as well as an advisor to the Engineering Professors' Council Recruitment Working Group. My experience of working with children also now means that I advise other research projects on ethical procedures and in particular on safeguarding vulnerable groups. This ensures that the learning from these publications will reach others who are interested in this area of work, and I will continue to influence practice throughout the science communication community.

7. Synthesis

Through this series of publications, I have developed my own critical academic and methodological understanding and skills as a researcher, as well as generated a body of novel work. The insights from these projects have proven applicable to both researchers and practitioners in the science communication and science education industries. In this section I will discuss the common themes arising from the publications, within the context of the overall aim of this DPhil, which is to develop a deeper psychological understanding of cultures of science communication at live science events in order to better support audiences and practitioners. Figure 1 represents how each publication contributes to the objectives described below.

Figure 1: Contribution of each publication to the aim and objectives of this DPhil



7.1 Audience perceptions of and needs for engagement formats and learning at live science events

The project which initiated this DPhil (publication A) has formed the foundation for much of my scholarly activity and research. The evaluation of Brain Day Auckland provided a deeper insight into audience needs and perceptions of live science events, as well as how to generate a culture of public engagement at a research centre in order to enable live science events to function. One of the key findings from this publication was that audiences attending the event were very satisfied with the formats and content on offer, and in particular, that they overwhelmingly preferred traditional one-way dissemination formats like lectures (Fogg-Rogers, Bay, Burgess, et al. 2015). This ran contrary to the consensus in the science communication literature at the time (Miller 2001; Meyer 2016), which has advocated for a movement towards dialogue and two-way engagement between audiences and STEM researchers.

Indeed, audiences were attending this science festival (Brain Day) in order to learn from experts; which situates these events within non-formal learning environments providing leisure-time or free-choice learning opportunities (Falk et al. 2007; Falk & Storksdieck 2005; Falk & Storksdieck 2010). This has proved critical to my future projects; understanding that audiences who attend live science events are generally already interested in STEM and want to know more about the latest research, including hearing from STEM researchers themselves.

However, this also highlighted that people who do not attend live science events are not already interested in STEM subjects. This may sound obvious, but in my experience it is still difficult to win scientists and engineers around to this way of thinking. Indeed, many scientists still conceptualise the 'general public' as distinct to scientists, without recognising varying forms of expertise in society (Meyer 2016). In particular, my research has reinforced other literature indicating that people with lower educational attainment, or who are from Black and Minority Ethnic groups, do not traditionally attend live science events. Dawson (2014) and Archer et al. (2015) attribute this to a cultural perception of who has social capital, indicating that 'science is not for people like them'. This indicates that there is much future work to be done exploring identity within STEM, particularly utilising Social Identity Theory (Tajfel 1974) to understand people who attend live science events, and those who do not.

This has therefore shaped many of my current projects, with a particular understanding that if you want to reach people who are not already interested in your topic, you have to find new ways of reaching and interesting them. This includes 'asset-based' communication (Whiting et

al. 2012), whereby a shared topic of interest between audiences and science communicators is generated and communicated, as well as 'place-based' communication (Gibson et al. 2017), whereby the live science events are taken to the places and venues where the audiences you want to reach are already present. This approach led to publication B about Māori Stroke Awareness. As part of a larger communication strategy to reach more people from Māori and Pacific Island backgrounds, our team realised we would first need to identify what these shared topics of interest were. As such, the publication identified current knowledge and awareness of stroke in Auckland, with the aim of generating communication strategies which would appeal to new audiences. This approach has also led to the communication strategy currently being deployed in the ClairCity project.

These findings were reinforced by the Science Live project (D). Interviews with science communication practitioners in the UK and USA confirmed observations from New Zealand, which is that live science events are popular with audiences, and there is a growing desire for similar events across each country. Audiences are coming to learn about new topics, and to meet with and hear from current STEM researchers. However, science communication practitioners often produce events which appeal to their personal desire for novelty (Durant et al. 2016); creating events which are creative and interactive without directly addressing their audience's preferences for non-formal learning.

Publication D also confirmed publication A's findings; that live science events across the UK and USA are not generally attracting people with lower educational attainment, or who are from Black and Minority Ethnic groups (Manning et al. 2013; Durant et al. 2016; Fogg-Rogers et al. 2015). While some live science events are experimenting with new venues and socially relevant topics in order to attract different audiences, it is difficult for the sector to learn from these findings. Science communication practitioners do not necessarily have time to read the latest research or to consistently attend other people's events, as they are so busy producing their own events. This has therefore been the focus of my current training programmes (Fogg-Rogers & Boushel 2017), aiming to share findings from science communication research in a format which practitioners can engage with and learn from.

7.2 Science communication cultures in STEM research environments and live science events

Through working in STEM research environments and organising many live science events, I have first-hand tacit experience of several science communication cultures. However, it is through analysing qualitative interviews for publications A, C, D and F that I have developed a deeper understanding of what helps or hinders the development of an ecosystem of public engagement. This is a term I used in Robots vs Animals (F), indicating that there will be many different types of science communication taking place within a STEM research environment, but that each form helps the others to grow and develop (Fogg-Rogers, Sardo & Boushel 2017).

While international science communication literature is concerned with debating which style of public engagement is preferable (Meyer 2016), my experience indicates that all forms of communication are beneficial for encouraging scientists and engineers to take part in public engagement. Live science events are particularly interesting as places where several styles of communication, learning, and engagement coincide at the same time, as discussed in Publication D (Durant et al. 2016). This reinforces the typology outlined by Rowe and Frewer (2005), whereby public communication involves one-way transmission from scientists/engineers to publics, which is exemplified by lectures. Public consultation involves scientists/engineers receiving information from the public, such as in a dialogue debate. Public participation is a transactional two-way process, whereby publics are actively involved and co-creating knowledge with scientists/engineers.

Another way of organising public engagement involves classifying different styles according to orders of thinking and interaction (Irwin 2008). First-order public engagement involves promoting awareness, interest, and learning, whereby scientists/engineers invite publics to learn more about their perspectives without themselves finding out more about public perspectives. Second order public engagement is dialogic, where information is exchanged and both scientists/engineers and publics are assumed to have valuable knowledge to offer. Third-order public engagement involves communication between multiple stakeholders in a wider sociocultural context, exploring how STEM can do the most good for society.

However, a limited view of first-order engagement and public communication as a ‘deficit model’ fails to take into account the concept that public engagement may be temporal, with interactions happening over time. In Publication A, I argued that organisational public engagement should be viewed on a continuum, whereby information flow enables and

facilitates interaction between publics and scientists (Fogg-Rogers, Bay, Burgess, et al. 2015). All methods of engagement are needed to fulfil this information flow; publics may wish to contribute to research dialogue and policy with their lay knowledge but may first want more scientific knowledge in order to do so. Live science events are well placed to nurture all forms of communication and engagement with public audiences. As such, I strongly argue that practitioners should stop feeling 'guilty' about organising lectures, and instead consider them within the context of an ecosystem and continuum of public engagement (Fogg-Rogers & Boushel 2017; Fogg-Rogers 2016; Fogg-Rogers, Bay, Burgess, et al. 2015).

This multi-faceted approach to public engagement was explored further in Publication C, applying the 'Complex Adaptive Systems' theory to the Centre for Brain Research (Herkema 2003). Many different styles of engagement took place at the same time, each contributing to the overall goal of engaging the public in research (France et al. 2015). Leadership was critical to enable this ecosystem of public engagement to develop, as was continued support from a science communication coordinator. Management techniques involved making open decisions and allowing others to control aspects of the organisation (the 'fishbowl' style of management), as well as the concept of 'tagging' and rewarding behaviours that you want to continue in an organisation. Indeed, sectoral leadership and research infrastructure are critical to support public engagement overall, as outlined in the discussion of research impact in Publication E (Fogg-Rogers, Grand & Sardo 2015).

Humans are social creatures, and are highly influenced by what they see, or perceive, other people like them are doing. This is why I have found Social Cognitive Theory (Bandura 1977) so useful in considering how to influence an organisational culture of public engagement. In Publication F (Fogg-Rogers, Sardo & Boushel 2017) I applied the learning taken from Publication C, and set in place a foundation of support for public engagement in the Bristol Robotics Laboratory. This included supportive leadership, a science communication coordinator, peer support networks, and rewards and recognition for engagement.

Vicarious experience is particularly important for women in STEM, as being a scientist or engineer has previously been considered a 'weird' thing for a women to undertake (O'Brien et al. 2016; O'Brien et al. 2017; Fara 2013). Publication F reinforced wider literature which indicates that peer support networks, supportive managers, and mentoring from more experienced co-workers are all critical to enable women to stay working in STEM careers (Fogg-Rogers, Sardo & Boushel 2017). For girls who are contemplating STEM as a career, women role models have been identified as 'inoculating against negative stereotypes' (Stout

et al. 2011), thereby enhancing the acceptability of becoming a scientist or engineer. In Publication G, I therefore argued that women need to become more visible in STEM in order to change perceptions about who becomes a STEM professional (Fogg-Rogers 2017b).

Live science events are particularly well placed to showcase women in STEM, with many platforms available to increase the visibility of scientists and engineers from diverse backgrounds. However, as outlined in Publication F, currently the sheer lack of women in STEM can place logistical demands on the women who are currently available for public engagement. Changing cultural norms can also mean than men may feel 'left-out' that they are not being deliberately selected for science communication activities (Fogg-Rogers, Sardo & Boushel 2017). Purposive selection of women, or positive discrimination, is a difficult agenda to progress, with many challenges along the way. However, as I argued in Publication G, social norms for women in STEM will not change unless deliberate efforts are made to improve the way we talk about and showcase women in STEM.

7.3 Evaluating and influencing the motivations and perceived self-efficacy of STEM researchers/students taking part in engagement and outreach

Much of my work has involved encouraging scientists and engineers to take part in public engagement, with research indicating that these activities are beneficial for both audiences and scientists/engineers (Callahan & Nadelson 2011; Direito et al. 2012). As previously discussed, live science events offer a fantastic environment to support these valuable interactions between scientists/engineers and publics, particularly as audiences are choosing to seek them out in their own leisure-time for non-formal learning (Jensen & Buckley 2014; Fogg-Rogers, Bay, Burgess, et al. 2015; Durant et al. 2016). School activities are also critical, as it is a unique opportunity to work with children from all social backgrounds and educational attainment, before learning becomes a free-choice activity in later life.

Whether or not scientists and engineers participate in public engagement activities depends on many factors, as outlined in Publications C, G and E; in particular feelings of enjoyment and personal efficacy, professional obligation, and a personal commitment to the public good are all critical (Besley et al. 2013). However, involvement in public engagement can be improved, as I illustrated in Publications F and H. Bandura's (2004) work on influencing perceived self-efficacy (PSE) through social cognitive means has proved critical in developing these projects. People with high PSE are more likely to continue performing that action, and so the projects I

have taken a leading role in have concentrated on providing experiences which have been shown to boost PSE.

Robots vs Animals (F) provided training and support for storytelling at live science events, while Children as Engineers (H) provided training and support for education outreach activities in schools. Through structured starter events, I aimed to enhance feelings of mastery through personal experience of success. Secondly, both projects involved peer support and mentoring support, enabling vicarious experience and social modelling. In both projects, the engineers involved indicated that they intended to continue performing public engagement activities. In Robots vs Animals (F), the engineers' PSE for education outreach significantly improved, while in Children as Engineers, the pre-service teachers' PSE for STEM teaching significantly improved.

In order to enhance participation in public engagement, I therefore argue that improving scientists' and engineers' PSE is an important goal for training programmes. This is why I developed and validated the Engineering Outreach Self-efficacy Scale in Publication I. Measuring engineering outreach PSE over time provides a way to evaluate the impact of science communication training programmes, which in turn means that engineers may take part in better quality and more frequent public engagement. I hope this empirical validated scale will form part of the toolkit for science communication researchers and practitioners in order to develop best practice in the field.

8. Conclusion

Through a series of nine publications, this DPhil has progressed academic knowledge into cultures of engagement at live science events for both practitioners and audiences. As outlined in my commentary, the experience of managing these projects and publishing the results has ensured that I meet the requirements of the UWE Doctoral Descriptors. The process has enhanced my skills as a researcher, and I feel a renewed sense of purpose to communicate these findings with the science communication community.

8.1 Future research and practice

As always in the research process, the projects have thrown up many interesting questions which I intend to take forward through my current and future research projects. As part of this DPhil I aimed to analyse audience perceptions of and needs for engagement formats and learning at live science events. The lessons outlined in my publications are currently informing my research practice in the ClairCity project and in the evaluations for the UK Science Festival Network.

Secondly, I aimed to explore science communication cultures in STEM research environments and live science events. Through my work with UWE Bristol researchers, I am applying this learning into the development of supportive research cultures aimed at changing social norms for public engagement. In particular, I am heavily involved with efforts across the West of England to mentor girls and women in STEM careers, aiming to provide supportive working environments for recruitment and retention. I intend to explore further the concepts of identity in STEM; looking at perceptions of belonging in STEM careers and at live science events, and drawing on Social Identity Theory.

Finally, I aimed to evaluate and influence the motivations and perceived self-efficacy of STEM researchers and students taking part in engagement and outreach. As well as applying Social Cognitive Theory within practical science communication environments, I have also developed a new scale to measure PSE for engineering education outreach. Through synthesising the varying theories and perspectives applicable to live science events, I have developed a deeper psychological understanding of science communication at live science events. I hope that this pragmatic approach to research, driven by my experience as a practitioner, will benefit both research and practice in science communication.

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9. References

Adams, R. et al., 2011. Multiple perspectives on engaging future engineers. *Journal of Engineering Education*, 100, pp.48–88.

Anderson, S.L. & Betz, N.E., 2001. Sources of Social Self-Efficacy Expectations: Their Measurement and Relation to Career Development. *Journal of Vocational Behavior*, 58, pp.98–117.

Andrews, E. et al., 2005. Scientists and public outreach: Participation, motivations, and impediments. *Journal of Geoscience Education*, 53, pp.281–293. Available at: http://cires.colorado.edu/education/outreach/rescipe/papers/andrewsJGE2005preprint.pdf.

Archer, L. et al., 2012. "Balancing acts'': Elementary school girls' negotiations of femininity, achievement, and science. *Science Education*, 96, pp.967–989.

Archer, L. et al., 2015. "Science capital": A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching*, 52(7), pp.922–948.

Bandura, A., 2006. Guide for constructing self-efficacy scales. In *Self-Efficacy Beliefs of Adolescents*. Information Age Publishing, pp. 307–337.

Bandura, A., 2004. Health promotion by social cognitive means. *Health Education & Behavior*, 31(2), pp.143–164.

Bandura, A., 1998. Health promotion from the perspective of social cognitive theory. *Psychology & Health*, 13, pp.623–649.

Bandura, A., 1997. Self-efficacy. *Harvard Mental Health Letter*, 13(9), p.4.

Bandura, A., 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psychological review*, 84, pp.191–215.

Bandura, A., 2001. Social cognitive theory of mass communication. *Media Psychology*, 3(3), pp.265–299. Available at: http://dx.doi.org/10.1207/S1532785XMEP0303_03.

Bandura, A., 1976. *Social Learning Theory*, Englewood Cliffs, NJ: Prentice Hall.

Bates, A.B., Latham, N. & Kim, J., 2011. Linking Preservice Teachers' Mathematics Self-Efficacy and Mathematics Teaching Efficacy to Their Mathematical Performance. *School Science and Mathematics*, 111, pp.325–333.

Bauer, M.W. & Jensen, P., 2011. The mobilization of scientists for public engagement. *Public*

Understanding of Science, 20(1), pp.3–11.

Bay, J.L. et al., 2015. Stroke awareness and knowledge in an Urban New Zealand population. *Journal of Stroke and Cerebrovascular Diseases*, 24(6).

Bensaude Vincent, B., 2014. The politics of buzzwords at the interface of technoscience, market and society: The case of "public engagement in science." *Public Understanding of Science*.

Besley, J.C. & Nisbet, M., 2011. How scientists view the public, the media and the political process. *Public Understanding of Science*.

Besley, J.C., Oh, S.H. & Nisbet, M., 2013. Predicting scientists' participation in public life. *Public Understanding of Science*, 22(8), pp.971–87.

Bleicher, R.E. & Lindgren, J., 2005. Success in science learning and preservice science teaching self-efficacy. *Journal of Science Teacher Education*, 16(3), pp.205–225.

Braun, V. & Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), pp.77–101.

Bristol Food Connections, 2014. Get Involved. Available at: http://www.bristolfoodconnections.com/get-involved/.

Bultitude, K., McDonald, D. & Custead, S., 2011. The Rise and Rise of Science Festivals: An international review of organised events to celebrate science. *International Journal of Science Education, Part B*, 1(2), pp.165–188.

Callahan, L.S. & Nadelson, J., 2011. A Comparison of Two Engineering Outreach Programs for Adolescents. *Journal of STEM Education: Innovations & Research. Jan-Mar 2011*, 12(1/2), pp.43–54.

Carrington, B. & McPhee, A., 2008. Boys' "underachievement" and the feminization of teaching. *Journal of Education for Teaching*, 34(2), pp.109–120.

Carter, K. et al., 2006. Trends in ethnic disparities in stroke incidence in Auckland, New Zealand, during 1981 to 2003. *Stroke; a journal of cerebral circulation*, 37, pp.56–62.

Centre for Brain Research, 2014. Our Vision. Available at: https://www.fmhs.auckland.ac.nz/en/faculty/cbr/our-centre/our-vision.html [Accessed July 29, 2014].

Child, N. et al., 2011. New Zealand National Acute Stroke Services Audit 2009: organisation of acute

stroke services in New Zealand. *Journal of the New Zealand Medical Association*, 124(1340), pp.13–20.

Crettaz von Roten, F., 2011. Gender Differences in Scientists' Public Outreach and Engagement Activities. *Science Communication*, 33, pp.52–75.

Dahlstrom, M.F., 2014. Using narratives and storytelling to communicate science with nonexpert audiences. *PNAS*, 111(4).

Davis, C.E., Yeary, M.B. & Sluss, J.J., 2012. Reversing the trend of engineering enrollment declines with innovative outreach, recruiting, and retention programs. *IEEE Transactions on Education*, 55(2), pp.157–163.

Dawson, E., 2014. Equity in informal science education: developing an access and equity framework for science museums and science centres. *Studies in Science Education*, 50(June 2016), pp.209–247. Available at: h.

Declerck, C.H., Boone, C. & De Brabander, B., 2006. On feeling in control: A biological theory for individual differences in control perception. *Brain and Cognition*, 62(2), pp.143–176.

Denscombe, M., 2010a. Mixed Methods. In *The Good Research Guide: for small-scale social research projects*. Maidenhead, UK: Open University Press, McGraw-Hill Education, p. 373.

Denscombe, M., 2010b. Questionnaires. In *The Good Research Guide: for small-scale social research projects*. Maidenhead, UK: Open University Press, McGraw-Hill Education, p. 373.

Department for Education, 2013. *Reform of the National Curriculum in England.*, Available at: https://www.gov.uk/government/publications/national-curriculum-in-england-primary-curriculum.

Diekman, A.B. et al., 2010. Seeking Congruity Between Goals and Roles: A New Look at Why Women Opt Out of Science, Technology, Engineering, and Mathematics Careers. *Psychological Science*, 21(8), pp.1051–1057.

Direito, I., Pereira, A. & Duarte, A.M. de O., 2012. Engineering Undergraduates' Perceptions of Soft Skills: Relations with Self-Efficacy and Learning Styles. *Procedia - Social and Behavioral Sciences*, 55, pp.843–851.

Donnellan, M.B. et al., 2006. The Mini-IPIP Scales: Tiny-yet-effective measures of the Big Five Factors of Personality. *Psychological Assessment*, 18(2), pp.192–203.

Dudo, A., 2013. Toward a Model of Scientists' Public Communication Activity: The Case of Biomedical

Researchers. *Science Communication*, 35(4), pp.476–501.

Duffy, J. et al., 2008. Service-Learning Projects in Core Undergraduate Engineering Courses. *Internation Journal for Service Learning in Engineering*, 3, pp.18–41.

Durant, J. et al., 2016. *Science Live: Surveying the landscape of live public science events*, Available at: https://livescienceevents.files.wordpress.com/2016/02/2016-science-live-landscape-survey.pdf.

Durant, J., 2013. The role of science festivals. *Proceedings of the National Academy of Sciences*, 110(8), p.2681.

Ecklund, E.H., James, S.A. & Lincoln, A.E., 2012. How academic biologists and physicists view science outreach. *PLoS ONE*, 7.

ENGINEER, E., 2015. Resources for schools. Available at: http://www.engineer-project.eu/download/index.html.

EngineeringUK, 2017. *The state of engineering*, Available at: https://www.engineeringuk.com/research/.

Falk, J. & Storksdieck, M., 2005. Using the Contextual Model of Learning to understand visitor learning from a science center exhibition. *Science Education*, 89, pp.744–778.

Falk, J.H. & Storksdieck, M., 2010. Science learning in a leisure setting. *Journal of Research in Science Teaching*, 47(2), pp.194–212.

Falk, J.H., Storksdieck, M. & Dierking, L.D., 2007. Investigating public science interest and understanding: evidence for the importance of free-choice learning. *Public Understanding of Science*, 16, pp.455–469.

Fara, P., 2013. Women in science: Weird sisters? *Nature*, 495(7439), pp.43–44.

Festival of Nature, 2014. Bigger, Better, Wilder. Available at: http://www.bnhc.org.uk/festival-of-nature/.

Flake, J.K., Pek, J. & Hehman, E., 2017. Construct Validation in Social and Personality Research. *Social Psychological and Personality Science*, 8(4), pp.370–378.

Flores, M.A. & Day, C., 2006. Contexts which shape and reshape new teachers' identities: A multi-perspective study. *Teaching and Teacher Education*, 22(2), pp.219–232.

Fogg-Rogers, L., 2017a. Are women part of mankind? *Science Communication Unit Blog*. Available at:

https://blogs.uwe.ac.uk/science-communication/are-women-part-of-mankind/.

Fogg-Rogers, L., 2017b. Does being human influence science and technology? *Journal of Science Communication*, 16(4).

Fogg-Rogers, L., Bay, J., Burgess, H., et al., 2015. "Knowledge Is Power": A Mixed-Methods Study Exploring Adult Audience Preferences for Engagement and Learning Formats Over 3 Years of a Health Science Festival. *Science Communication*, 37(4), pp.419–451.

Fogg-Rogers, L., 2016. *Scientists in person: Live science events*, London.

Fogg-Rogers, L. & Boushel, C., 2017. *Event Public Engagement Guide*, Available at: http://www1.uwe.ac.uk/research/sciencecommunicationunit/coursesandtraining/practitionerguides.aspx.

Fogg-Rogers, L., Edmonds, J. & Lewis, F., 2015. *Children as engineers: Paired peer mentors in primary schools final report summary July 2015*, London, UK. Available at: http://eprints.uwe.ac.uk/26053/.

Fogg-Rogers, L., Grand, A. & Sardo, M., 2015. Beyond dissemination - Science communication as impact. *Journal of Science Communication*, 14(3).

Fogg-Rogers, L., Lewis, F. & Edmonds, J., 2017. Paired peer learning through engineering education outreach. *European Journal of Engineering Education*, 42(1).

Fogg-Rogers, L., Sardo, M. & Boushel, C., 2017. Robots vs Animals: establishing a culture of public engagement and female role modelling in a multi-disciplinary engineering laboratory. *Science Communication*, 39(2).

Fogg-Rogers, L., Sardo, M. & Boushel, C., 2015. *Robots vs animals: Learning from the ingenuity of nature. Final summary report.*, London, UK. Available at: http://eprints.uwe.ac.uk/26062/.

France, B., Cridge, B. & Fogg-Rogers, L., 2015. Organisational Culture and Its Role in Developing a Sustainable Science Communication Platform. *International Journal of Science Education Part B*, pp.1–15.

Gibson, A., Welsman, J. & Britten, N., 2017. Evaluating patient and public involvement in health research: from theoretical model to practical workshop. *Health Expectations*.

Grant, L., 2004. *Evaluation of Cheltenham Festival of Science 2004*,

Haven, K., 2007. *Story Proof*, Libraries Unlimited.

HEFCE, 2014. Research Excellence Framework. Available at: http://www.ref.ac.uk/.

Herkema, S., 2003. A Complex Adaptive Perspective on Learning within Innovation Projects. *The Learning Organization*, 10(6), pp.340–346.

Holliman, R. et al., 2009. *ISOTOPE: Informing Science Outreach and Public Engagement. Final Report of the NESTA-funded ISOTOPE Project.*, Milton Keynes, UK.

House of Lords Select Committee on Science and Technology, 2000. *Science and Society - Third Report*, Available at: http://www.publications.parliament.uk/pa/ld199900/ldselect/ldsctech/38/3802.htm.

Irwin, A., 2008. Risk, science and public communication: Third-order thinking about scientific culture. In M. Bucchi & B. Trench, eds. *Handbook of Public Communication of Science and Technology*. Oxford, UK: Routledge, pp. 199–212.

Jeffers, A.T., Safferman, A.G. & Safferman, S.I., 2004. Understanding K–12 Engineering Outreach Programs. *Journal of Professional Issues in Engineering Education and Practice*, 130(2), pp.95–108.

Jensen, E. & Buckley, N., 2014. Why people attend science festivals: Interests, motivations and self-reported benefits of public engagement with research. *Public Understanding of Science*, 23(5), pp.557–573. Available at: http://pus.sagepub.com/content/23/5/557.abstract.

Johnson, D.R., Ecklund, E.H. & Lincoln, A.E., 2014. Narratives of Science Outreach in Elite Contexts of Academic Science. *Science Communication*, 36(1), pp.81–105.

Laura Grant Associates, 2010. *Walking with Robots Final Evaluation Report*, Available at: http://collectivememory.britishscienceassociation.org/wp-content/uploads/2011/11/Walking-with-Robots-Overall-Evaluation.pdf.

Laursen, S. et al., 2007. What good is a scientist in the classroom? Participant outcomes and program design features for a short-duration science outreach intervention in K-12 classrooms. *CBE life sciences education*, 6, pp.49–64.

Lockwood, P., 2006. “Someone like me can be successful”: do college students need same-gender role models? *Psychology of Women Quarterly*, 30(1), pp.36–46.

Manning, C. et al., 2013. *The Science Festival Alliance: Creating a Sustainable National Network of Science Festivals. Final Summative Evaluation Report.*, Cambridge, MA.

Marcinkowski, F. et al., 2014. Organizational Influence on Scientists’ Efforts to Go Public: An

Empirical Investigation. *Science Communication*, 36(1), pp.56–80.

Martin-Sempere, M.J., Garzon-Garcia, B. & Rey-Rocha, J., 2008. Scientists' motivation to communicate science and technology to the public: surveying participants at the Madrid Science Fair. *Public Understanding of Science*, 17, pp.349–367.

Martínez-Jiménez, P. et al., 2010. OPEE: An outreach project for engineering education. *IEEE Transactions on Education*, 53(1), pp.96–104.

Mcmullan, M., Jones, R. & Lea, S., 2012. Math anxiety, self-efficacy, and ability in British undergraduate nursing students. *Research in Nursing and Health*, 35(2), pp.178–186.

Meyer, G., 2016. In science communication, why does the idea of a public deficit always return? *Public Understanding of Science*, 25(4).

Miller, S., 2001. Public understanding of science at the crossroads. *Public Understanding of Science*, 10, pp.115–120.

Ministry of Business Innovation and Employment, 2014. National Science Challenges. Available at: http://www.msi.govt.nz/update-me/major-projects/national-science-challenges/.

Molina-Gaudo, P. et al., 2010. Perception and intention in relation to engineering: A gendered study based on a one-day outreach activity. *IEEE Transactions on Education*, 53(1), pp.61–70.

Murphy, P. & Whitelegg, E., 2006. *Girls in the physics classroom: a review of the research on the participation of girls in physics.*, London, UK. Available at: http://oro.open.ac.uk/6499/1/girls_and-physics.

National Coordinating Centre for Public Engagement, 2014. What is public engagement? Available at: http://www.publicengagement.ac.uk/what/.

National Institutes for Health and Northwestern University, 2016. NIH Toolbox. Available at: http://www.healthmeasures.net/explore-measurement-systems/nih-toolbox/obtain-and-administer-measures.

Neale, D.C., Smith, D. & Johnson, V.G., 1990. Implementing Conceptual Change Teaching in Primary Science. *The Elementary School Journal*, 91(2), p.109.

O'Brien, L.T. et al., 2016. Improving Girls' Sense of Fit in Science. *Social Psychological and Personality Science*, 8(3), pp.301–309.

O'Brien, L.T. et al., 2017. Improving Girls' Sense of Fit in Science: Increasing the Impact of Role

Models. *Social Psychological and Personality Science*, 8(3), pp.301–309.

Oakes, W. et al., 2002. Service-learning in engineering. *32nd Annual Frontiers in Education*, 2.

Office of Science and Technology, 2004. *UK Science Festivals: PEST or not?*, London, UK.

Ofsted, 2011. *Successful Science.*, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/413802/Successful_science.pdf.

Owen, D. & Hill, S., 2011. *Embedding Public Engagement in the Curriculum: A Framework for the Assessment of Student Learning from Public Engagement*, Available at: https://www.publicengagement.ac.uk/sites/default/files/Assessing student learning from PE.pdf.

Palmer, S.E. & Schibeci, R.A., 2012. What conceptions of science communication are espoused by science research funding bodies? *Public Understanding of Science*.

Perkins, J., 2013. *Professor John Perkins' Review of Engineering Skills*, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/254885/bis-13-1269-professor-john-perkins-review-of-engineering-skills.pdf.

Pickering, M. et al., 2004. The Benefit of Outreach to Engineering Students. In *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*.

Poliakoff, E. & Webb, T.L., 2007. What Factors Predict Scientists' Intentions to Participate in Public Engagement of Science Activities? *Science Communication*, 29(2), pp.242–263.

RCUK, 2010. *Concordat for Engaging the Public with Research*, Available at: http://www.rcuk.ac.uk/per/Pages/Concordat.aspx.

RCUK, 2015. Impact Requirements. Frequently Asked Questions. Available at: //www.ahrc.ac.uk/Funding-Opportunities/Documents/RCUKImpactFAQ.pdf.

Riise, J., 2008. Bringing science to the public. In D. Cheng et al., eds. *Communicating Science in Social Contexts: New Models, New Practices*. Springer, pp. 301–309.

Robertson Evia, J. et al., 2017. Validating a scale that measures scientists' self-efficacy for public engagement with science. *International Journal of Science Education, Part B*, pp.1–13.

Rowe, G. & Frewer, L.J., 2005. A Typology of Public Engagement Mechanisms. *Science, Technology & Human Values*, 30(2), pp.251–290.

Royal Society, 2010. *The Scientific Century: securing our future prosperity*, London, UK. Available at: https://royalsociety.org/policy/publications/2010/scientific-century/.

Science Communication Unit, 2018. About Us. Available at: http://www1.uwe.ac.uk/research/sciencecommunicationunit/aboutus.aspx.

Science in Public, 2015. Research, Practice, Impact. Available at: https://scienceinpublic.org/conferences/sip2015/.

Stapleton, W. et al., 2009. A novel engineering outreach to high school education. In *Proceedings - Frontiers in Education Conference, FIE*.

Statistics New Zealand, 2013. *2013 Census Quick Stats*, Available at: http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-national-highlights/cultural-diversity.aspx.

Stilgoe, J., Lock, S.J. & Wilsdon, J., 2014. Why should we promote public engagement with science? *Public understanding of science (Bristol, England)*, 23, pp.4–15.

Stout, J.G. et al., 2011. STEMing the tide: using ingroup experts to inoculate women's self-concept in science, technology, engineering, and mathematics (STEM). *Journal of personality and social psychology*, 100(2), pp.255–270.

Tajfel, H., 1974. Social identity and intergroup behaviour. *Social Science Information*, 13(65).

Terämä, E. et al., 2016. Beyond academia - Interrogating research impact in the research excellence framework. *PLoS ONE*, 11(12).

TNS, 2015. *Factors affecting public engagement by researchers*, Available at: https://wellcome.ac.uk/sites/default/files/wtp060033_0.pdf.

Trench, B., 2008. Towards an Analytical Framework of Science Communication Models. In *Communicating Science in Social Contexts*. Springer Netherlands, pp. 119–135.

Trench, B. & Miller, S., 2012. Policies and practices in supporting scientists' public communication through training. *Science and Public Policy*, 39(6), pp.722–731.

University of the West of England, 2014. Bristol Bright Night. Available at: http://info.uwe.ac.uk/events/event.aspx?id=16135.

Watermeyer, R., 2012. From Engagement to Impact? Articulating the Public Value of Academic Research. *Tertiary Education and Management*, 18(2), pp.115–130.

Weihe, B., 2014. When science makes us who we are: known and speculative impacts of science festivals. *Journal of Science Communication*, 13(4).

Wellcome Trust, 2014. Festivals. Available at: http://www.wellcome.ac.uk/Funding/Public-engagement/Engagement-with-your-research/Support-and-resources/Festivals/index.htm [Accessed December 19, 2014].

Whiting, L., Kendall, S. & Wills, W., 2012. An Asset-Based Approach: An Alternative Health Promotion Strategy? *Community Practitioner*, 85(1), pp.25–28.

Wilkinson, C. & Sardo, S., 2013. *Killer Facts for Informal Learning*, Available at: http://www.wellcome.ac.uk/Education-resources/Education-and-learning/News/2013/WTP053966.htm.

Wynne, B., 2006. Public engagement as a means of restoring public trust in science - Hitting the notes, but missing the music? In *Community Genetics*. pp. 211–220.

Yoon Yoon, S., Evans, M.G. & Strobel, J., 2014. Validation of the Teaching Engineering Self-Efficacy Scale for K-12 Teachers: A Structural Equation Modeling Approach. *Journal of Engineering Education*, 103(3), pp.463–485.

Zeldin, A.L., Britner, S.L. & Pajares, F., 2008. A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *Journal of Research in Science Teaching*, 45, pp.1036–1058.